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Observations on the Trout-Perch *Percopsis omiscomaycus* (Walbaum), at Heming Lake, Manitoba[1]

By G. H. Lawler
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ABSTRACT

Trout-perch of Heming Lake attain III years of age and 90 mm. in fork length. In May they ascend small tributaries to spawn on silt and boulder bottoms, at a temperature of 40°–50°F. Average egg content was 349, with range 210–728 in 11 fish. Trout-perch taken in the lake were infested with 0 to 6 cysts each (av. 1.4) containing plerocercoids of the cestode *Triaenophorus stizostedionis*. Most cysts were in the liver or gonads, very few in the muscle. Trout-perch were eaten in large numbers by pike, *Esox lucius*, and much less frequently by walleye, *Stizostedion vitreum*. Only the latter contained adult *Triaenophorous stizostedionis*.

INTRODUCTION

The trout-perch *Percopsis omiscomaycus* is widely distributed throughout the Nearctic regions and appears to be a fairly important food item in the diet of several species of fish. Attention was given to this fish at Heming Lake, Manitoba when it was found to harbour the larval stage of the pseudophyllidean cestode *Triaenophorus stizostedionis*, recently described by Miller (1945). The data on the trout-perch were collected during 1950, 1951 and 1952 while investigating the biology of *Triaenophorus* for the Central Fisheries Research Station.

Heming Lake, situated on the Precambrian Shield, in the Province of Manitoba, at 54°53′ N. lat., 101°07′ W. long., is 588 acres in area, three miles in length from north to south and one-quarter to one-half mile in width. It lies in the headwaters of the Grass River, a tributary of the Nelson River which flows into Hudson Bay. Depths do not exceed 19 feet, the water is slightly acid and brownish and visibility is about six feet.

THE TROUT-PERCH

Spawning

During May 1950 and 1951 trout-perch were observed ascending two tributaries of the lake. The smallest of these, on the west side of the lake, was approximately one-quarter mile long, three feet wide and two feet deep. The flow of water was fairly swift during the spring run-off. The creek bottom was, for the most part, silty. This creek was blocked with a make-shift trap, made of a wooden box with a wire-screen top and with one side opening into a conical funnel which allowed the fish to enter but not to leave the box. The trap was set on May 17, 1950, May 14, 1951, and May 7, 1952. Water temperatures were taken with a recording thermometer located in the water near the trap. During part of the investigational period the trap was examined twice daily, at 8:00 A.M.

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and 8:00 P.M., C.S.T. There did not appear to be any significant difference between day and night movement up the creek. In addition, the trap was lifted several times during various other hours of the day and night; however no evidence of unusual diurnal activity was noted. The catch and sex ratio of trout-perch per day and the daily maximum water temperatures are shown in Table I. An obstruction near the mouth of the creek in 1951 may have prevented some

TABLE I. Catch of trout-perch, sex ratio and daily maximum and minimum water temperatures (deg. F.) during the observational period.

	1950				1951				1952		
May	No. of fish	Sex ratio	Min. temp.	Max. temp.	No. of fish	Sex ratio	Min. temp.	Max. temp.	No. of fish	Min. temp.	Max. temp.
		♂/♀				♂/♀					
14	—	—	—	—	109	76/33	40	46	0	40	50
15	—	—	—	—	21	19/2	36	42	0	43	50
16	—	—	—	—	29	26/3	37	45	0	47	49
17	—	—	—	—	79	71/8	42	51	0	47	53
18	96	18/10	42	47	41	39/2	45	46	6	45	53
19	42	—	40	50	0	—	—	—	—	45	52
20	445	221/224	40	50	—	—	—	—	9	43	52
21	331	115/216	43	52	—	—	—	—	0	40	50
22	—	—	—	—	—	—	—	—	2	39	43
23	2	—	—	—	—	—	—	—	0	36	43

fish from coming up the creek. In 1952 the creek was examined throughout its length when the trap was placed in the water and no obstacles were noted, but later in the season when it became evident that the run was going to be light further examination showed the foundation of a beaver dam near the creek mouth. The decline in numbers of trout-perch ascending the creek in 1951 and 1952 may have resulted from an actual decrease in numbers or may have been due to obstructions preventing entry up the creek.

In 1950, at another larger creek at the northwest end of the lake, trout-perch were observed in very large numbers. This creek was quite shallow, with a boulder bottom. The quiet eddies behind the boulders contained masses of trout-perch. Each fish appeared to be attempting to reach the bottom of the dense mass. The fish were pointed head downwards and their caudal fins were in continual motion. Although milt and eggs could be extruded from these fish with very little pressure, indicating an advanced state of ripeness, it cannot be stated that the actual spawning act was observed since eggs and milt were not seen flowing freely from the fish at this time. The fish may have been milling behind the boulders to counteract the force of the current. In 1950 the white sucker *Catostomus commersoni* was spawning in this creek at the same time. In 1951 and 1952 the trout-perch were not observed in this creek, although the sucker and yellow walleye, *Stizostedion v. vitreum*, were seen spawning there.

The sex ratio of trout-perch captured at the creek on the west side of the lake during the 1950 sampling period was 354 males to 450 females. In 1951 the ratio was 231 males to 48 females.

Fecundity

The ovaries of 19 trout-perch were collected for egg counts. Eight of these were in an advanced state of ripeness and were discarded to avoid bias. Total egg counts made on 11 fish are given in Table II. These fish contained an average of 349 eggs per individual; the largest individual count was 728 and the smallest was 210.

Table II. Number of eggs, average diameter of eggs, and the weights and lengths of 11 trout-perch from Heming Lake, 1951.

Fork length	Total weight	Number of eggs	Av. diam. of eggs
mm.	*g.*		*mm.*
60	3.1	279	1.25
61	3.2	210	1.41
63	—	242	0.80
64	3.5	332	1.40
64	4.0	342	1.40
68	—	275	1.40
68	4.3	308	—
70	4.9	298	—
71	4.9	350	1.35
76	7.3	475	1.30
78	8.1	728	1.45

Age Composition and Length Frequency

Age determination of a few randomly selected trout-perch showed only three age groups present. Age group II comprised 70.8 per cent of the sample, with age groups I and III contributing 25 and 4.2 per cent respectively.

The fork lengths of 146 trout-perch measured in 1951 ranged from 55 millimetres to 90 millimetres, with a mean length of 74.5 millimetres. The majority of the fish were between 65 and 75 millimetres in length.

Parasitism with *Triaenophorus*

The adult stage of the tapeworm *T. stizostedionis* occurs in the intestine of the yellow walleye *Stizostedion v. vitreum*. The tapeworm matures in the spring, sheds its eggs and dies. The eggs hatch into coracidia and are ingested by the copepod *Cyclops bicuspidatus*, in which the coracidia become procercoids. If the copepods are eaten by trout-perch the worm becomes encysted in the visceral and parietal peritoneum and is then called a plerocercoid. The life history is completed when an infected trout-perch is consumed by a yellow walleye. During 1950 and 1951 at Heming Lake, Miller's (1945) findings on the second intermediate and final stages of the life history were verified. In 1950, 94 trout-perch

were examined for *T. stizostedionis* and 63.8 per cent were parasitized with a total of 85 cysts (an average of 1.4 cysts per infected fish). In 1951, 46 trout-perch were examined and 48 per cent were infected with a total of 33 cysts (an average of 1.5 cysts per infected fish). The greatest number of cysts observed in one fish was six. One cyst examined contained five plerocercoids. The position of the cysts within the body of the trout-perch is extremely variable, as is shown in Table III. The liver was the commonest place of attachment. Very few cysts were found in the flesh, which is the usual location of cysts of *Triaenophorus crassus* in the coregonines.

TABLE III. Position and frequency of cysts of *T. stizostedionis* in the trout-perch of Heming Lake, 1951.

Position	Frequency
Liver	47
Gonads	30
Stomach	9
Intestine	6
Pyloric caeca	6
Heart	3
Peritoneum	3
Gullet	2
Hypaxial muscle	3
Epaxial muscle	1

The trout-perch, abundant near shore during the early spring, did not appear too frequently in the stomachs of the final host, the yellow walleye. The major food item of the northern pike *Esox lucius* during May and June was the trout-perch, as many as 63 trout-perch having been found in one pike. Despite the large quantities of trout-perch ingested by pike, *T. stizostedionis* was never found in the pike, thus supporting the theory of host preference.

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Catch and Winter Food of Lake Trout in certain Algonquin Park Lakes[1]

By N. V. Martin
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ABSTRACT

Winter catches of lake trout in the sports fishery exceeded those taken at other times of the year in some Algonquin Park lakes. The size of the fish caught was generally smaller because of the different type of gear used in winter. The winter fishing also exploited a high percentage of the immature stock.

The winter diet was less varied than at other seasons and there was a high percentage of empty stomachs. Bottom feeding was negligible in most lakes, but, in some, insect larvae were taken more frequently than at any other time of the year. Plankton feeding was at a low level in winter even in those lakes which have predominantly plankton-feeding populations in summer. In these same lakes the absence of thermal barriers permitted trout to feed more frequently on fish in winter and also on a greater variety of fish species. Populations feeding on fish in summer continued to do so in winter. As the winter progressed, there was a decline in the frequency of plankton in the stomachs and an increase in fish and bottom fauna.

INTRODUCTION

Our knowledge of the life history of the lake trout *Salvelinus namaycush namaycush* is still imperfect and indeed is almost a complete void for that part of the year when ice covers our lakes. Studies aimed at filling this gap in our information have been carried on by the Research Division of the Ontario Department of Lands and Forests in the Algonquin Park area. Two features of these studies will be discussed—the catch statistics of the ice fishing and the winter food of the lake trout—and these will be compared with summer conditions.

THE WINTER FISHERY

The winter sports fishery for lake trout has become increasingly popular in late years in southern Algonquin Park. Because of the difficulties in reaching the lakes in the winter months most of the angling has been confined to about a dozen lakes within a mile of the highway which passes through the southern corner of the Park. An increasing part of the fishing in late years is being done by fishermen entering the Park from towns as far as 70 or 80 miles away. The local people of course have fished the area for many years but in general they fish a wider range of lakes, including some of the more inaccessible waters.

The fishing technique is similar to that employed elsewhere. Minnow-baited lines are attached to slender four-foot gads placed at a 45-degree angle over a hole about a foot in diameter. A strike is indicated by the violent bending of the tip of the pole.

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The availability of the lake trout in winter is generally higher than that at other times of the year, particularly in smaller lakes. This is due in part to the greater size range of trout available in the winter fishery. In large lakes like Lake Opeongo (13,400 acres), the catch is usually low, possibly because of difficulty in locating the fish.

Although there are no accurate catch data, rough estimates have been made for several of the lakes. In Brewer Lake (109 acres) the catch in the winter of 1950–51 was estimated to be 50 lake trout. In Canisbay Lake (350 acres) in the same year an estimated 800 lake trout were taken. Its catch in 1952–53 probably exceeded 1,000 lake trout. Costello Lake (96 acres) rewarded the angler with approximately 50 lake trout in 1952. All these catch figures far exceed the angling returns for the remainder of the year in these lakes.

In Figure 1 a comparison is made between the size composition of the angler's catch made by ice fishing and the composition of the catch taken by trolling at other seasons. The winter fishing, in three of the lakes at least, takes a much higher percentage of small lake trout. In Canisbay Lake 60 per cent of the lake trout in winter were 12 inches and under (fork length) while this group made up only 15 per cent of the summer catch. The average length of the winter fish was 11.9 inches, the summer 14.7 inches. In Lake Louisa this same size group of fish formed 50 per cent of the ice-fishing catch (average length 12.4 inches) and 10 per cent of the summer catch (average length 14.5 inches). In Brewer and Costello lakes there are insufficient trolling returns at a similar period to the winter collections for a comparison, but it is evident there is a high percentage of small fish, particularly in Costello Lake. In Lake Opeongo a somewhat different situation exists as the size of the fish taken through the ice is somewhat greater than that of those by trolling. Probably the fact that anglers on this lake use large hooks and minnows in the hope of catching large lake trout has some bearing on this situation.

Figure 1 also gives an indication of the proportion of mature and immature fish in the catch. Canisbay lake trout first mature at about 12 inches and Louisa at 11 inches, and both at age 5. It is evident then that the winter fishing exploits a high percentage of the immature stock in both these lakes. In Brewer and Costello lakes between half and two-thirds of the winter catch is made up of immature fish.

The difference in the ice-fishing and trolling catches is of course related to the differences in the gear used. The summer trolling, using heavy metal lines and large trolls or spinners, regulates the size of lake trout caught, so that in such lakes as Canisbay and Louisa, where the trout mature at a small size, the summer fishery leaves an appreciable part of the mature stock to spawn each fall. This situation will be changed because of winter fishing methods which take smaller fish and hence a greater proportion of the immature stock.

WINTER FOOD OF THE LAKE TROUT

A total of 442 lake trout stomachs was collected from a series of 18 Algonquin Park lakes, 20 by gill-netting, the remainder by the winter sports fishery. These data are summarized in Table I.

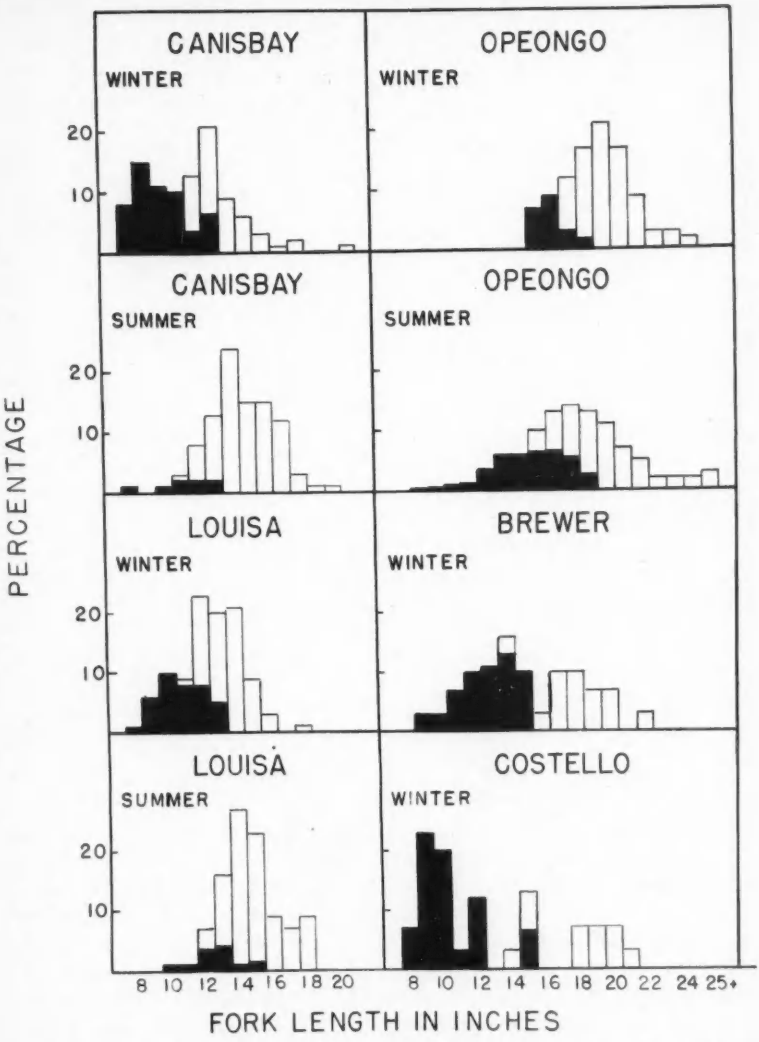

FIGURE 1. The size composition of the ice-fishing catch compared with that at other times of the year. The black areas represent the proportion of immature lake trout at each length.

In Table II the winter food is compared with that at other times of the year for those lakes where there are sufficient data. As the diet of the lake trout varies seasonally the data have been split into four major periods, spring (May and June), summer (July and August), fall (September and October) and winter.

TABLE I. Analysis of lake trout stomachs collected from certain Algonquin Park lakes in winters of 1948–52.

Lake	Number collected	Number containing food items indicated					
		Empty	Plankton	Insect larvae	Fish	Bait minnows	Crayfish
Boot	21	6	1	2	12	4	0
Booth	11	6	0	0	5	0	0
Brewer	33	17	0	0	16	10	0
Butt	8	8	0	0	0	2	0
Canisbay	77	15	33	17	22	11	0
Costello	38	22	9	0	8	13	0
Fraser	11	3	0	3	5	3	0
Hay	9	7	0	0	2	2	0
Joe	1	1	0	0	0	0	0
Kathlyn	1	0	0	0	1	1	0
Kearney	2	1	0	0	1	0	0
Lobster	5	2	0	0	2	3	0
Louisa	117	27	14	27	68	28	0
Opeongo	83	32	2	1	50	3	0
Shirley	5	0	0	0	4	0	1
Source	3	0	2	0	1	0	0
Sylvia	5	0	0	0	2	3	4
Two Rivers	12	6	0	0	6	2	0
Total	442	153	61	50	205	85	5

The winter diet differs from that at other times. Although it is much less varied because of the absence of surface feeding, there is also less variety in the bottom and pelagic feeding. In Brewer and Costello lakes the percentage of empty stomachs was at its highest, except for the fall months, and it was generally high in the other lakes. The data in Table I suggest that there was less feeding activity in winter.

Plankton feeding was generally at a low level in winter. In Lake Louisa, which has a predominantly plankton-feeding population in summer, only one trout in nine took plankton during the period of ice cover. Bottom feeding was almost negligible in three of the five lakes. In two lakes, Louisa and Canisbay, insect larvae occurred more frequently than at any other time of the year. Mayfly larvae were the chief components of the bottom organisms in the stomachs, as they were at other seasons. Crayfish were also taken on occasion.

The use of bait minnows in the ice-fishery made the analysis of the fish diet difficult, particularly when a lake was fished over a period of time. Where fish in trout stomachs have been definitely identified as bait minnows they have been indicated as such in the data presented. They have not been included in the fish percentages, and where they are the only food in the stomach the trout has been considered to be empty.

It is evident that in most of the lakes fish play an important part in the winter diet. This is particularly striking in the case of Lake Louisa where fish

TABLE II. Percentage frequency of occurrence of winter foods, compared with other times of the year.

Lake	Number examined	Empty	Plankton	Insect larvae	Fish	Surface
Louisa						
Spring	40	4	23	19	31	19
Summer	298	15	73	7	15	3
Fall	111	33	40	1	26	0
Winter	117	23	12	23	58	0
Canisbay						
Spring	18	22	61	11	22	6
Summer	134	13	54	11	35	1
Fall	0	—	—	—	—	—
Winter	77	19	43	22	29	0
Brewer						
Spring	84	10	40	11	49	4
Summer	103	12	39	4	65	0
Fall	63	22	60	2	24	0
Winter	33	52	0	0	48	0
Costello						
Spring	34	5	27	24	35	11
Summer	21	16	13	16	71	0
Fall	9	0	88	0	0	0
Winter	38	58	24	0	21	0
Opeongo						
Spring	266	34	4	7	70	6
Summer	345	44	0	0	56	0
Fall	42	55	0	0	43	0
Winter	83	38	3	1	61	0

were taken four times as often as in the summer. In Louisa in summer the trout feed largely on plankton, since minnows, the only forage fish, are in shallow water and largely unavailable to them. With the breakdown of thermal barriers in fall and winter, minnows are taken more frequently. The Lake Opeongo trout, which are predominantly fish feeders at other times of the year, are also strong fish feeders in winter. Only in Costello was there any drop in the number of fish-feeding trout in winter.

As might be expected there is a difference in the species composition of the forage fish in winter. The absence of temperature barriers permits lake trout to feed on species partly or entirely unavailable to the trout during thermal stratification. Perch occurred twice as frequently as whitefish in Opeongo trout in winter, whereas in summer the reverse is generally although not always true. Minnows were also taken on occasion at this time in this lake, whereas they were only rarely eaten in summer. Similarly there was a sixfold increase in minnows in the stomachs of Brewer Lake trout. Pumpkinseed were very rarely taken in winter although they were eaten in summer.

In Table III an attempt has been made to show that food habits may change during the winter. This seems rather surprising, since we generally assume that conditions under ice are rather static. However the changes are more a change in the frequency in which certain food elements occur than a change to other forms.

TABLE III. Percentage frequency of occurrence of food items in stomachs of lake trout in winter months.

Lake	Period	Number examined	Percentage containing food items indicated			
			Empty	Plankton	Insect larvae	Fish
Louisa	January 16, 17	24	21	38	13	42
	February 12	22	27	18	23	45
	March 10, 23	30	17	3	40	66
Canisbay	December 17	12	0	75	8	25
	January	10	20	80	0	10
	February 18	11	0	100	0	0
	March 28, 29	20	25	10	20	55
	April 6, 7	24	33	13	17	21
Opeongo	January	15	7	7	7	93
	February	30	53	3	0	43
	March	30	45	0	0	55
	April	6	0	0	0	100

There appears to be a general increase in the number of empty stomachs as the winter progresses. There are, however, definite trends in the abundance of plankton, fish and insect larvae in the stomachs. The frequency of occurrence of plankton in the stomachs decreases as the winter progresses. In Lake Louisa, where a year-round study of feeding habits has been carried out by Martin (1952), it is evident that the incidence of plankton in the stomachs is correlated with the classical plankton cycle. Peaks in the frequency of plankton in the stomachs occur in early June and late October and low points in late August and March. Data provided by Dr. Langford of the Ontario Fisheries Research Laboratory show that certain zooplankters in samples from these lakes, particularly copepods and cladocerans, decrease throughout the winter until in March and April they may be only a fifth as abundant as in October. Fish in the stomachs showed a steady increase in frequency of occurrence throughout the winter at least up until the end of March. The increased proportion of fish-feeding trout in late winter is probably associated with a decreasing abundance of plankton.

REFERENCE

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European Ling—First Record from North American Waters[1]

By Wilfred Templeman and A. M. Fleming
Newfoundland Fisheries Research Station, St. John's, Nfld.

ABSTRACT

A European ling, 137 cm. long, caught on the Grand Bank, February, 1953, is identified as *Molva molva*. This is the first substantiated record from North American waters south of Greenland.

INTRODUCTION AND INFORMATION

On February 9, 1953, the otter-trawler *Zibet* landed an unusual fish in Burin, Newfoundland. The fish had been caught on the southwestern part of the Grand Bank approximately in Lat. 44°43′ N. and Long. 53°19′ W. at a depth of 48 to 55 fathoms between February 3 and 8, 1953.

The fish was 54 in. (137 cm.) long and the weight, whole, was 37½ pounds. It was a female, dark slate on back and yellowish grey on the abdomen. The fish was photographed in a gutted condition and then unfortunately discarded. One otolith was kept. The above information and observations were obtained by Mr. S. Butler, station technician at Burin. Figure 1 shows two lateral views of the fish in the gutted condition.

DISCUSSION AND CONCLUSIONS

Identification

From the pictures and also the otolith the fish was obviously a European ling, genus *Molva*, and as far as can be determined a new record for the western Atlantic south of Greenland. The otolith was compared with that of *Molva molva* in the paper by Scott (1906) and was similar in shape to the otolith of this species. From the literature, particularly from the account in the *Faune ichthyologique* of *Molva molva* by Tåning (1938), of *Molva byrkelange* by Schnakenbeck (1930) and of *Molva elongata* by d'Ancona (1931), it was possible to determine that the fish resembled in all its characters *Molva molva* and not the other two species. Frazer-Brunner and Palmer of the British Museum (Natural History) have recently (1951) published the result of a study of the three species of *Molva* from the west coast of Ireland, the common European ling *Molva molva*, the Scandinavian deep-water species *Molva byrkelange* and the Mediterranean form *Molva macrophthalma* (formerly *elongata*). Mr. Palmer has examined the photographs of the Newfoundland ling and has written in a personal letter as follows:

> As far as can be ascertained from photographs your specimen is undoubtedly an example of *Molva molva* (L). My reasons for identifying the specimen as *Molva molva* are as follows:
>
> 1. The pelvic fin does not reach to the tip of the pectoral fin. [Pelvic reaches beyond tip of pectoral in *macrophthalma*.]

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2. The length of the head is contained less than five times in the length of the fish [5.0 to 5.9 times in *macrophthalma*].

3. The base of the second dorsal is about 4½ times that of the first dorsal [5.3 to 7.5 times longer in *byrkelange*].

4. There is a dark patch on the hind edge of the first dorsal, and the margins of the second dorsal, anal and caudal fin is edged with white. [No white edging on dorsal, anal and caudal in *byrkelange* and *macrophthalma* and the black edging of the first dorsal is not present in *byrkelange*.]

The notes in brackets above are our own, from Frazer-Brunner and Palmer (1951).

Dr. Einar Koefoed of the Institute of Marine Research, Directorate of Fisheries, Bergen, Norway, after seeing the photographs, also agrees that the fish captured on the Grand Bank was *Molva molva*.

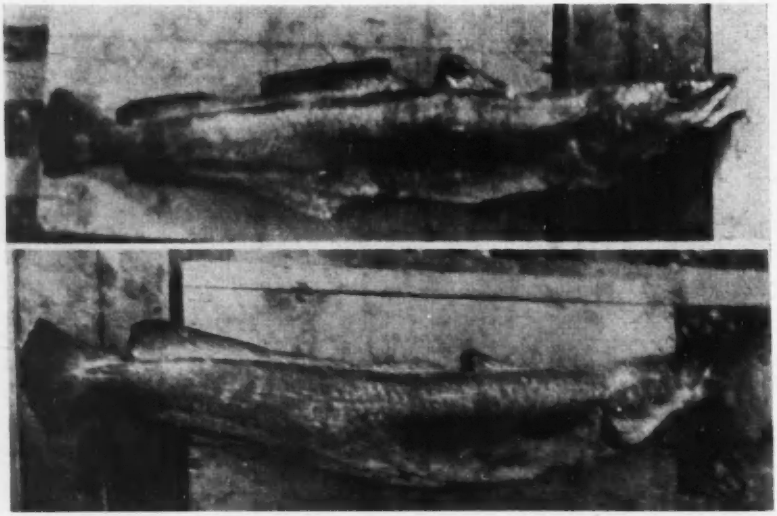

FIGURE 1

DISTRIBUTION OF MOLVA MOLVA

Frazer-Brunner and Palmer (1951) say that the genus *Molva* is confined to the eastern North Atlantic and the Mediterranean. Tåning (1938) says of *Molva molva* that its distribution is in the eastern Atlantic from northern Norway and Iceland to the Bay of Biscay; penetrating into the western Baltic but not occurring in the western Atlantic. Jensen (1938) has examined two specimens of *Molva molva* from south Greenland and gives reports of the capture of other specimens. He gives the distribution as the northern Atlantic, in Europe from the Murman coast to northern and western France, also the Faroes, Iceland, Newfoundland. Goode and Bean (1895) say of the species "it is said to have been found in the deep water off Newfoundland but we have been unable to find the specific

record". Jordan and Evermann (1898) repeat the above statement of Goode and Bean. Since Jensen gives the paper of Jordan and Evermann as a reference it is apparently from this source that he includes Newfoundland as a part of the range of the ling. Mr. Palmer of the Fish Division of the British Museum (Natural History) in a personal letter regarding our specimen says that this appears to be the first substantiated record of this species from the Grand Bank and the first for the genus from North American waters. Dr. H. B. Bigelow of the Harvard Museum of Comparative Zoology who has examined our photographs says that he is quite sure that we are right in thinking that this is the first record of a *Molva* from American waters. In southern Newfoundland the white hake *Urophycis tenuis* is called the ling. This species is quite common in deep water on the southern part of the Grand Bank and near the south coast of the island, and the unsubstantiated record of Goode and Bean may have been due to this ambiguity in common names. Fishermen from the eastern United States had a close association with the Grand Bank and the south coast of Newfoundland during the nineteenth century.

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Surface Tidal Currents in Juan de Fuca Strait[1]

By R. H. Herlinveaux[2]
Pacific Naval Laboratory and Pacific Oceanographic Group

ABSTRACT

Surface-current measurements were made at half-hour intervals throughout thirty-hour periods at three positions in Juan de Fuca Strait. These were repeated during spring and neap ranges of the tide in spring, summer and late autumn during 1952. The currents are linear functions of the difference of sea level between the Pacific Ocean and the Strait of Georgia. A rule is given for predicting the currents from data in the Tide Tables.

INTRODUCTION

During 1952 several series of current observations were made in Juan de Fuca Strait to determine the nature of the tidal velocity cycle at the surface and at a number of depths to 100 fathoms. The surface data are the more complete and definitive, and are discussed here without regard to the deep currents, which will be discussed in a later report.

The surface currents are proportional to the difference of sea level from the Ocean Coast to the Strait of Georgia. From this study a rule has been developed for predicting the direction and velocity of these currents from the data in the Tide Tables (1).

THE SURVEYS

It was the general plan of the study to obtain current profiles in a cross-section of the Strait in the early spring when the southwest winds were dominant and the land drainage was small; in the summer when the winds were light and the river discharges were large; and in the autumn when the northwest winds were dominant. Measurements were made at three stations (A, B, and C in Figure 1) in a line across the Strait. The currents were observed every half hour throughout a 30-hour period, and the stations were occupied during successive days. In each series the currents in the cross-section (A, B, C) were observed during spring and neap tides, in spring, summer and autumn, as catalogued in Table I.

The program was not ideal in every sense. Owing to the prevalence of fog in these waters, particularly during the summer and autumn, it was not possible to anchor in exactly the same position for successive observations at a station. The greatest variation of position occurred in the central station (B) and the uncertainties arising from this will be discussed later.

Procedure

The time of survey was chosen so that the three stations (A, B, C) being observed on successive days would fall in the middle of a period of spring tides,

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FIGURE 1. Juan de Fuca Strait and vicinity showing stations A, B, and C where velocity observations were made, and tidal reference stations at Clayoquot, Victoria and Point Atkinson.

and during the following (or preceding) week, they would occur in the middle of a period of neaps. The tidal heights at Victoria during the observations are shown in Figure 2.

The ship was secured by a single bow anchor and allowed to swing with the tide. Unsuccessful attempts were made to anchor by bow and stern, and to set a sea anchor astern to mitigate the effects of cross winds. These laborious precautions were abandoned when it became evident that satisfactory measurements could be obtained without them.

Surface-current measurements were made with a 16-foot drift pole (2). It was weighted at one end to float with about two feet above water, and was secured by a light line marked in 100-foot intervals. The pole was allowed to

TABLE I. Catalogue of surface current observations in Juan de Fuca Strait, 1952.

Station	Latitude (N)	Longitude (W)	Date	Hours of observation
	Spring series – spring tides			
A	48°21′04″	123°50′01″	Mar. 19,20/52	24
B	48°18′35″	123°57′45″	Mar. 20,21/52	30
C	48°13′45″	124°01′00″	Mar. 17,18/52	27
	Spring series – neap tides			
A	48°21′00″	123°56′05″	Mar. 10,11/52	27
B				
C	48°13′45″	124°01′00″	Mar. 11,12,13/52	31
	Summer series – spring tides			
A	48°20′30″	123°56′12″	July 2,3/52	28
B				
C	48°13′48″	124°00′54″	July 3,4/52	22
	Summer series – neap tides			
A				
B	48°18′00″	124°00′00″	July 5,6/52	29
C	48°14′00″	124°00′24″	July 6,7/52	27
	Autumn series – spring tides			
A	48°21′12″	123°57′00″	Oct. 17,18/52	24
B	48°18′06″	123°58′30″	Oct. 14,16/52	30
C	48°13′48″	124°00′18″	Oct. 16,17/52	30
	Autumn series – neap tides			
A	48°21′00″	123°56′12″	Oct. 23,24/52	28
B	48°17′30″	123°58′24″	Oct. 20,21/52	30
C	48°14′00″	124°00′00″	Oct. 22,23/52	25

drift away from the ship with the current. The velocity was determined by noting the time required for the pole to drift a measured distance (300 to 500 feet) and the direction of drift was observed.

The procedure was easy when the ship was lying steady in the tidal stream, but was more difficult when the ship lay across the stream as a result of wind pressure, or when the ship yawed from side to side. When the ship was steady, a short run of the drift pole was sufficient to determine the current within 0.1 knots. When the ship was unsteady the pole was allowed to drift during several complete yaws, so that the release and final timing were made when the ship was in the same position. Observations were abandoned whenever it became impossible to compensate for the movement of the ship in this manner. It is estimated that the accuracy of the observations is generally ± 0.1 knots, although the error may exceed this limit in isolated cases.

The data were catalogued (3) and plotted as functions of time (Figure 3C) and as hodographs (Figure 8).

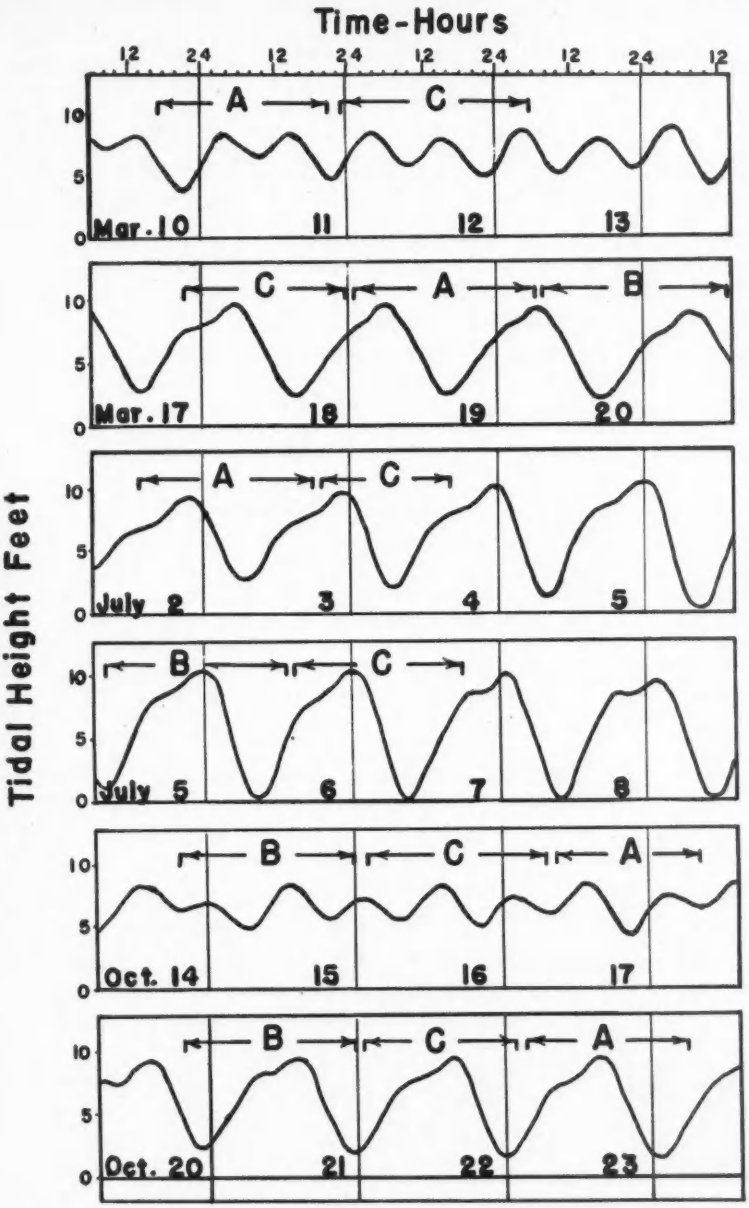

FIGURE 2. Tides at Victoria during periods of current observations.

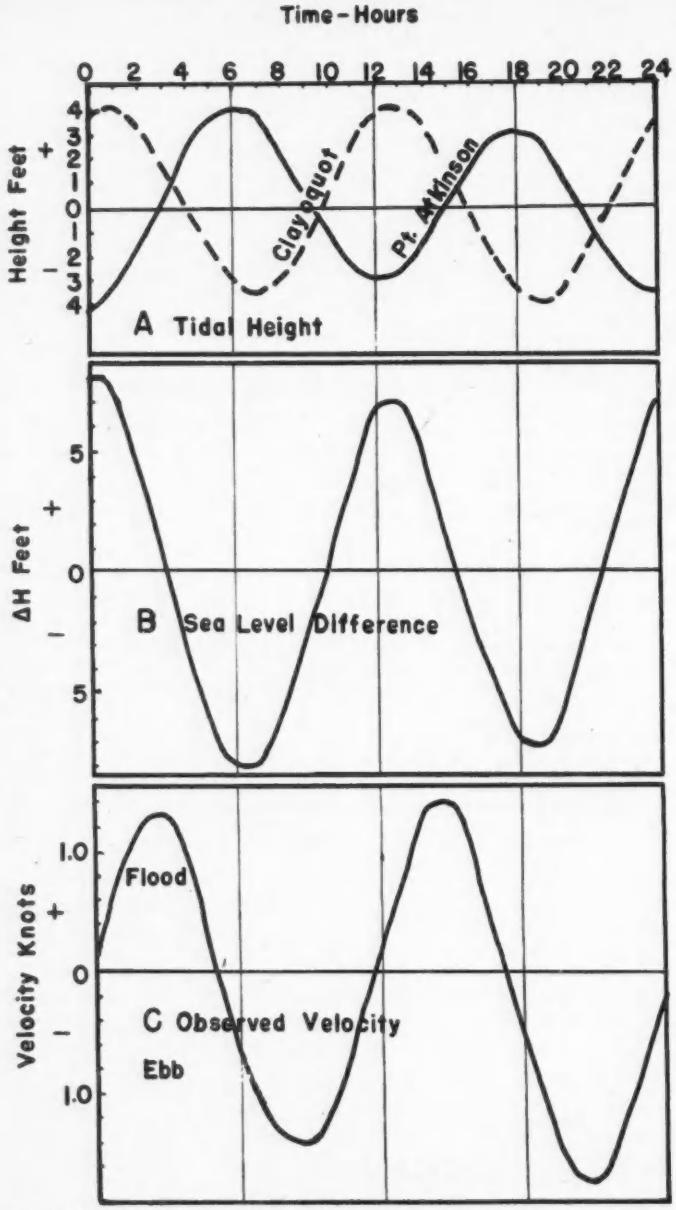

FIGURE 3. Tidal-height and current data, October 16, 17, 1952.

A. Plot of tidal heights at Clayoquot and Point Atkinson referred to mean sea level.

B. Difference of height of the sea surface between Clayoquot and Point Atkinson.

C. Observed velocity function.

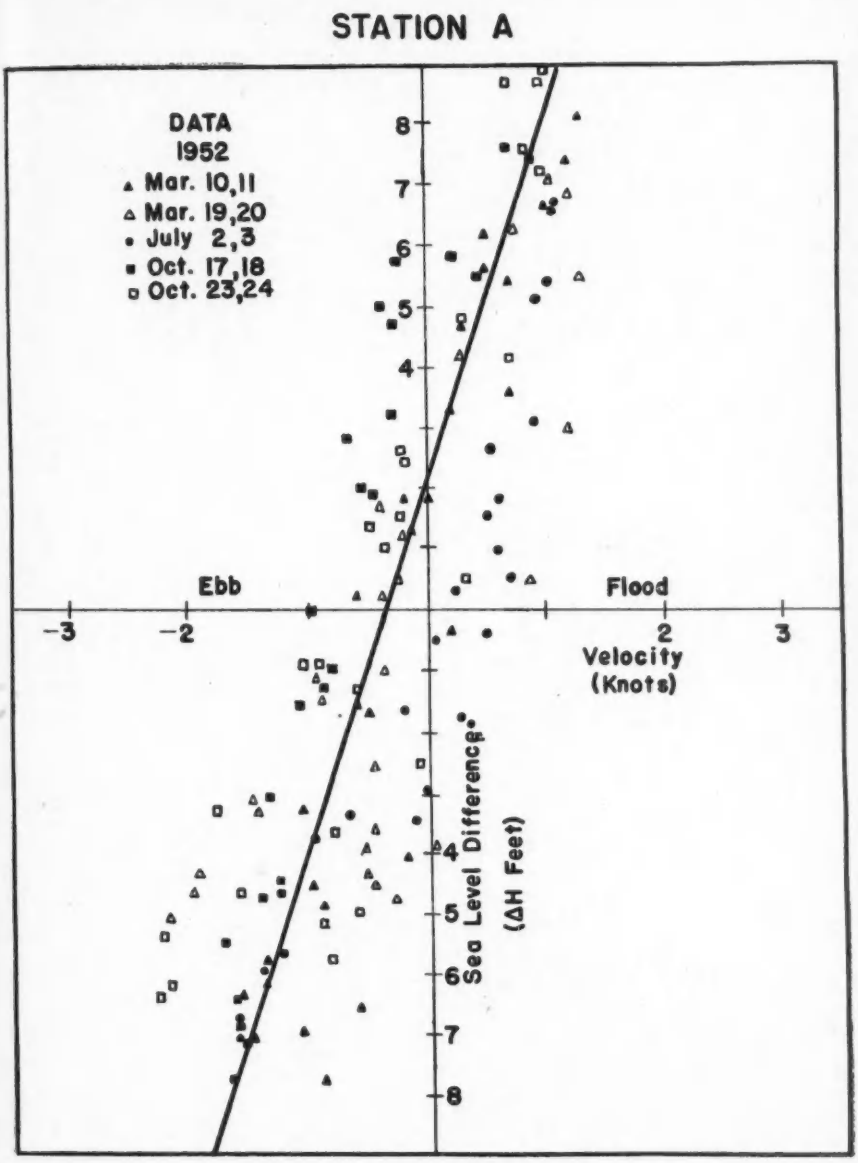

FIGURE 4. Observed tidal-current velocities at station A plotted as a function of the sea-level difference from Clayoquot to Point Atkinson.

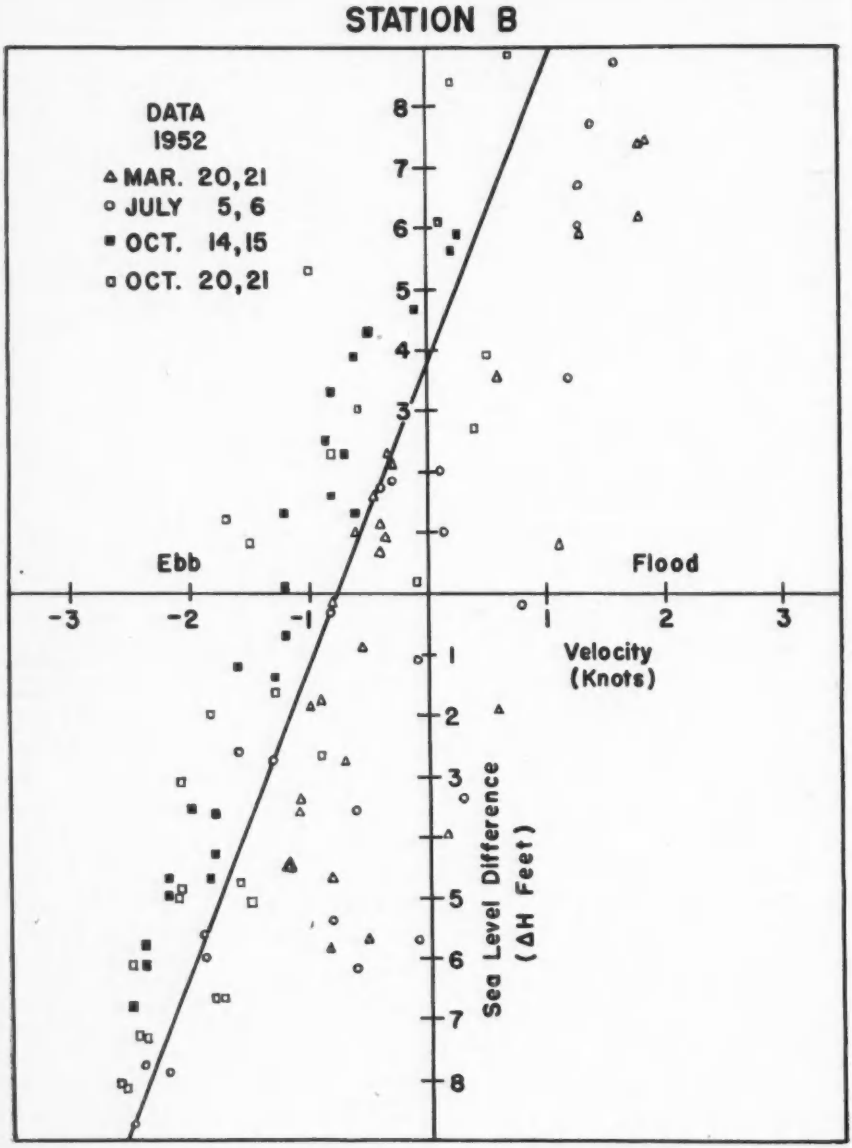

FIGURE 5. Observed tidal-current velocities at station B plotted as a function of the sea-level difference from Clayoquot to Point Atkinson.

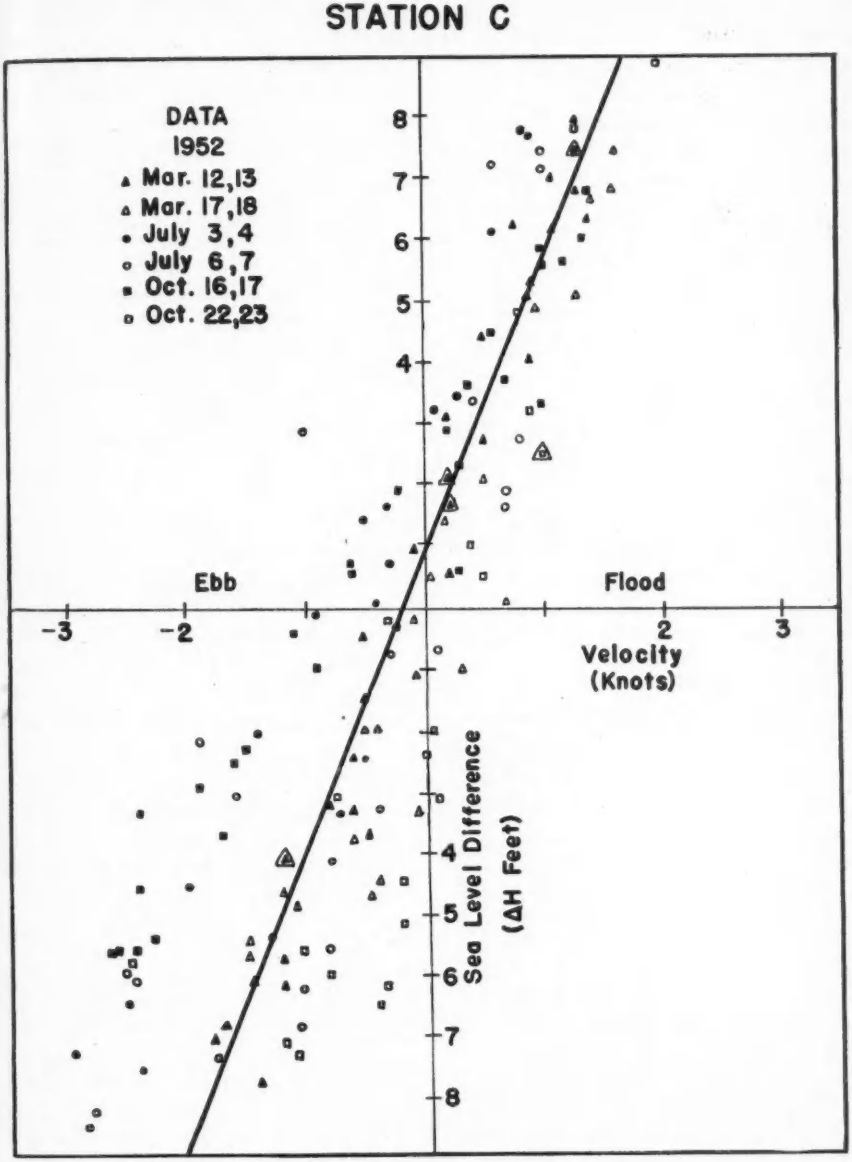

FIGURE 6. Observed tidal-current velocities at station C plotted as a function of the sea-level difference from Clayoquot to Point Atkinson.

THE OBSERVED RELATIONS

In general the tidal currents wax and wane, and reverse direction in a cycle of the same period as the tide, as shown in Figure 3. In order to determine the nature of the currents, the observed velocities were compared with the difference of sea level (ΔH) between Clayoquot on the Ocean Coast and Point Atkinson in the Strait of Georgia. These are primary tidal stations for which the predictions are given directly in the Tide Tables. The tides are so nearly synchronous along the Ocean Coast that the Clayoquot data may be assumed to represent the tides at the seaward entrance to Juan de Fuca Strait.

The tidal heights at the reference points were referred to mean sea level (4) and plotted as functions of time (5) (Figure 3A). The difference of height (ΔH) was taken at hourly intervals and plotted as shown in Figure 3B, and compared to the velocity function shown in Figure 3C. It may be noted that the functions are parallel with a lag of 130 minutes. Adjusting for this lag the velocity was plotted as a function of the difference of tidal height (ΔH) as shown in Figures 4, 5 and 6, and the best straight line was fitted to the points by the method of least squares.

On further examination it was found that all the data from one station during the spring and neap tides of the spring, summer and autumn series could be combined in one diagram without materially altering the probable error. These data show that the tidal velocity (V) is approximately a linear function of the difference of sea level (ΔH) between the reference points, of the form:

$$V = k \,.\, \Delta H + c$$

when the time scale of the two functions is shifted so that the maxima are coincident. The equations of the relations, the probable error and the time lags at stations A, B and C are shown in Table II.

A similar relation, but with a greater scatter of points, was derived when the difference of sea level was taken from Clayoquot to Victoria. This increased scatter was probably associated with the indeterminate maxima in the tide cycle (Figure 2) which are common to all tidal stations near the inner end of Juan de Fuca Strait. These make it difficult to make the plot of the tide curves with the necessary precision.

ERRORS

It is probable that the greater part of the error is due to the wide separation of the tidal reference points, but no better data are available, and these must be accepted.

The relations of Figures 4, 5 and 6 were determined from the observed tide curves at Clayoquot and Point Atkinson. Previously the relation was deduced from analysis of the predicted data in the Tide Tables which differed by as much as a foot from the observed data. This relation was considerably less precise and was abandoned.

The positions occupied by the ship on each successive survey are listed in Table I. The side stations A and C varied over a distance of more than a mile

TABLE II. The relation between tidal velocities (V) and the difference of tidal height (ΔH) from Clayoquot to Point Atkinson, the time lag (G(t)) and the probable error of the relation.

Relation	Probable error
	Knots
STATION A	
$V = 0.2\Delta H - 0.4$	± 0.4
Lag = 140 minutes	
Direction Ebb 287°T, Flood 107°T	
STATION B	
$V = 0.2\Delta H - 0.8$	± 0.4
Lag = 130 minutes	
Direction Ebb 290°T, Flood 110°T	
STATION C	
$V = 0.2\Delta H - 0.2$	± 0.4
Lag = 120 minutes	
Direction Ebb 294°T, Flood 114°T	

along the length of the Strait. Considering that the channel is straight and regular in this region it is unlikely that this variation is significant. However the positions occupied at station B in mid-stream varied by more than a mile across the stream and as much as three miles longitudinally. It is believed that this variation is significant and contributed materially to the greater scatter of the velocity-tidal difference relation shown in Figure 5.

WIND EFFECTS

Most of the observations were made during periods of light winds, but the data of July 2 and 3 were collected during strong westerly winds, and those of October 17 and 18 during strong easterly winds. These data are shown in Figures 7A and 7B.

Evidently the wind effect is appreciable when the tidal current is small, and is small when the tidal current is greater than one knot. The wind component (Vw) appears to be of the order of

$$Vw = 0.015\ (W\text{-}V)$$

where (W-V) is the difference between the wind velocity (W) and the normal current velocity (V). This is consistent with Ekman's estimate of the velocity of wind-driven currents (8).

From casual observations made while working in the area it appears that a westerly wind caused a current in the flood direction during the first few hours of its duration. Apparently this built up a "head" in the Puget Sound region which opposed the wind current so that the wind effect appeared to diminish, although the wind was still blowing. When the wind died down, a strong relaxation current in the ebb direction occurred as the "head" was dissipated. However there are not sufficient data to evaluate these phenomena.

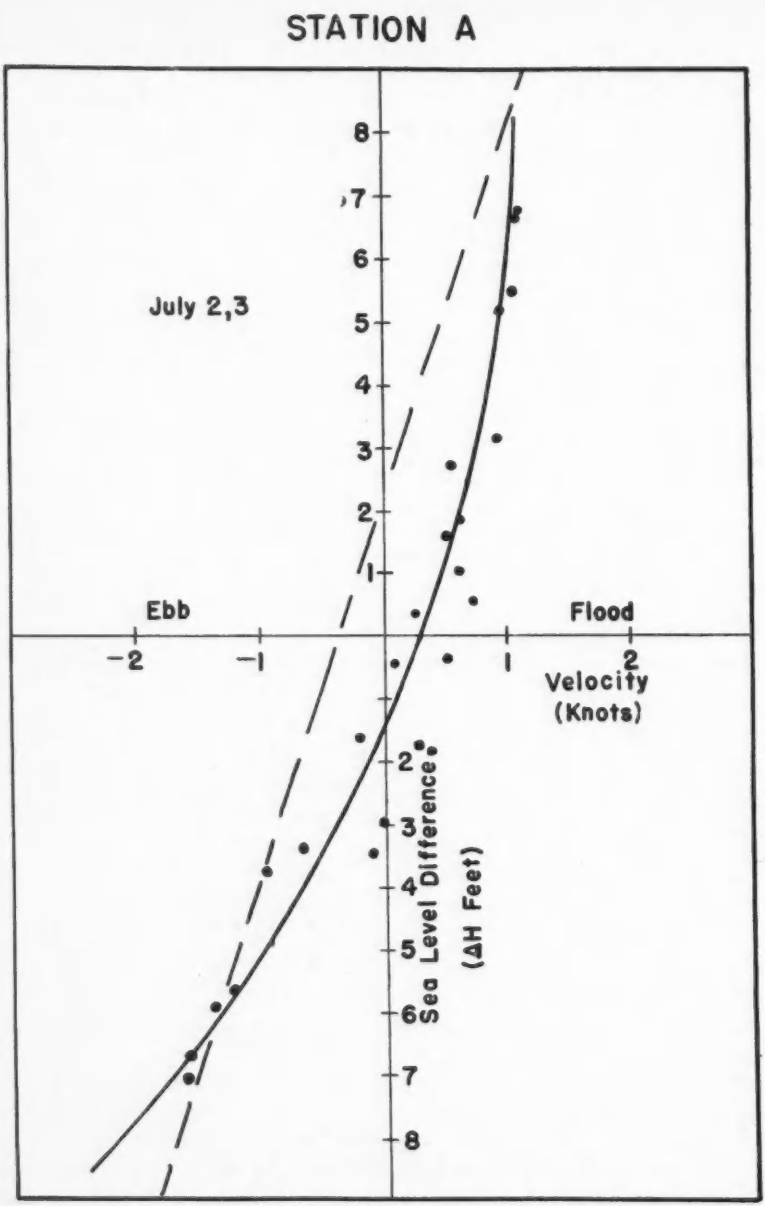

FIGURE 7A. The relation of velocity in Juan de Fuca Strait to the difference of tidal height from Clayoquot to Point Atkinson during strong westerly winds, July 2 and 3, 1952.

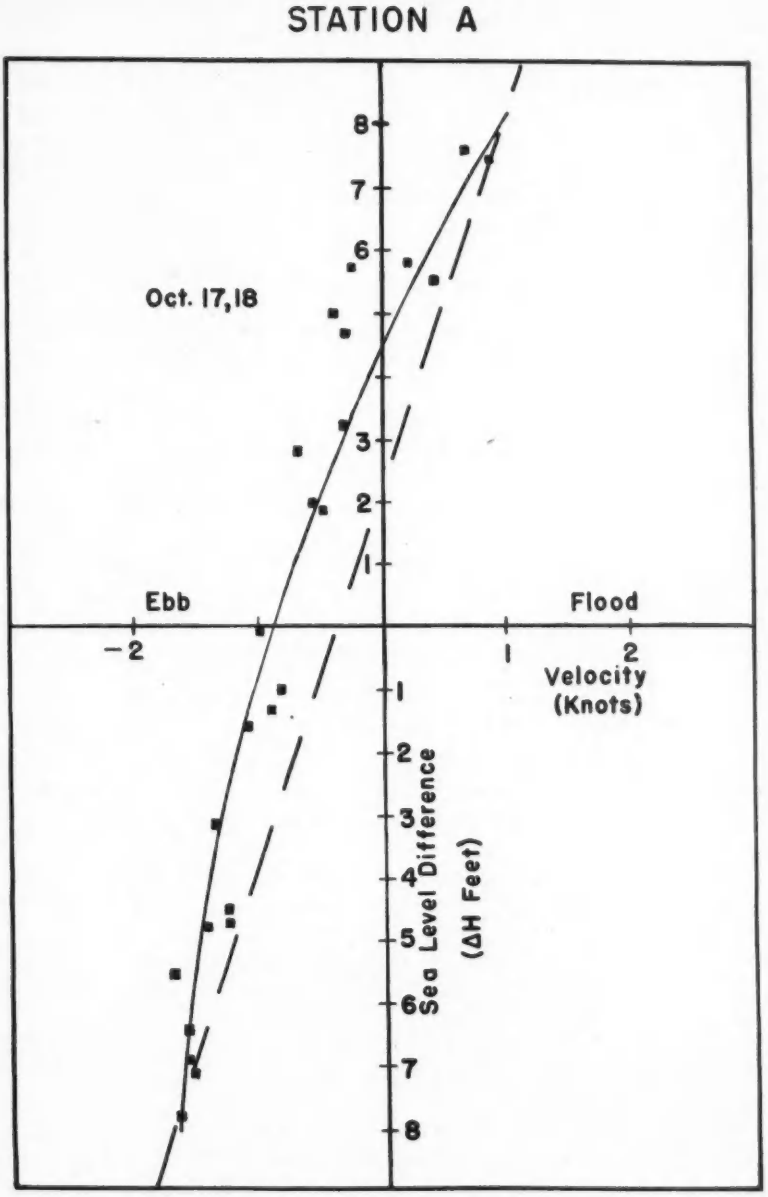

FIGURE 7B. The relation of velocity in Juan de Fuca Strait to the difference of tidal height from Clayoquot to Point Atkinson during strong easterly winds, October 17 and 18, 1952.

Rotation of Tidal Currents

In general the tidal currents in Juan de Fuca Strait are reversing; however there is some evidence of rotation as shown in Figure 8. Although these hodographs present a confused picture, it can be seen that the rotary components are greatest at station B in mid-channel and least at the side stations A and C. Evidently the rotary characteristics of the tidal current at Swiftsure Light-vessel (2) at the entrance to Juan de Fuca Strait persist for some distance into the Strait, until they are suppressed by the boundaries.

Because of this rotary characteristic there is no period of truly slack water; rather the currents are directed across the channel with an appreciable velocity. This accounts for some of the scatter of the points in the velocity-time relation, and in the velocity-tidal height relation in Figures 4, 5 and 6.

The Ebb Bias

It is notable in the data that the ebb flow endures longer, and is stronger than the flood. This ebb bias must be due to fresh-water run-off from the land, or be a characteristic of the surface current.

The run-off of the Fraser River is about five times greater in June than in the early spring or late autumn (9), and if the ebb bias of the currents were due to run-off it would be expected to be materially greater in the June survey than in the others. Since there was no observed difference in this bias in the three periods of survey it is concluded that the influence of run-off on the surface current is inconsequential.

CONCLUSIONS

The Tidal Current

The character of the tidal current is illustrated by the relation of the calculated tidal current cycles in Figure 9. The flood and ebb streams are nearly equal along the southern shore (station C) but in the centre (station B) the ebb stream is the stronger.

The form of the flood and ebb velocity profiles corresponding to sea-level differences of eight feet ($\Delta H = 8$ feet) are shown in Figure 10.

The duration of the tidal-current cycle is the same at all stations, and the lag of the current maxima increases by 10 minutes from the southern side (station C) to mid-channel (station B) and again to the northern side (station A). These are illustrated in Figure 9, and summarized in Table III.

It is evident that the tidal currents in Juan de Fuca Strait can be simply related to the difference of sea level between Clayoquot and Point Atkinson.

Prediction of Tidal Currents

On the basis of this study simple rules are provided for the prediction of surface currents in this cross-section of Juan de Fuca Strait, with an accuracy of half a knot.

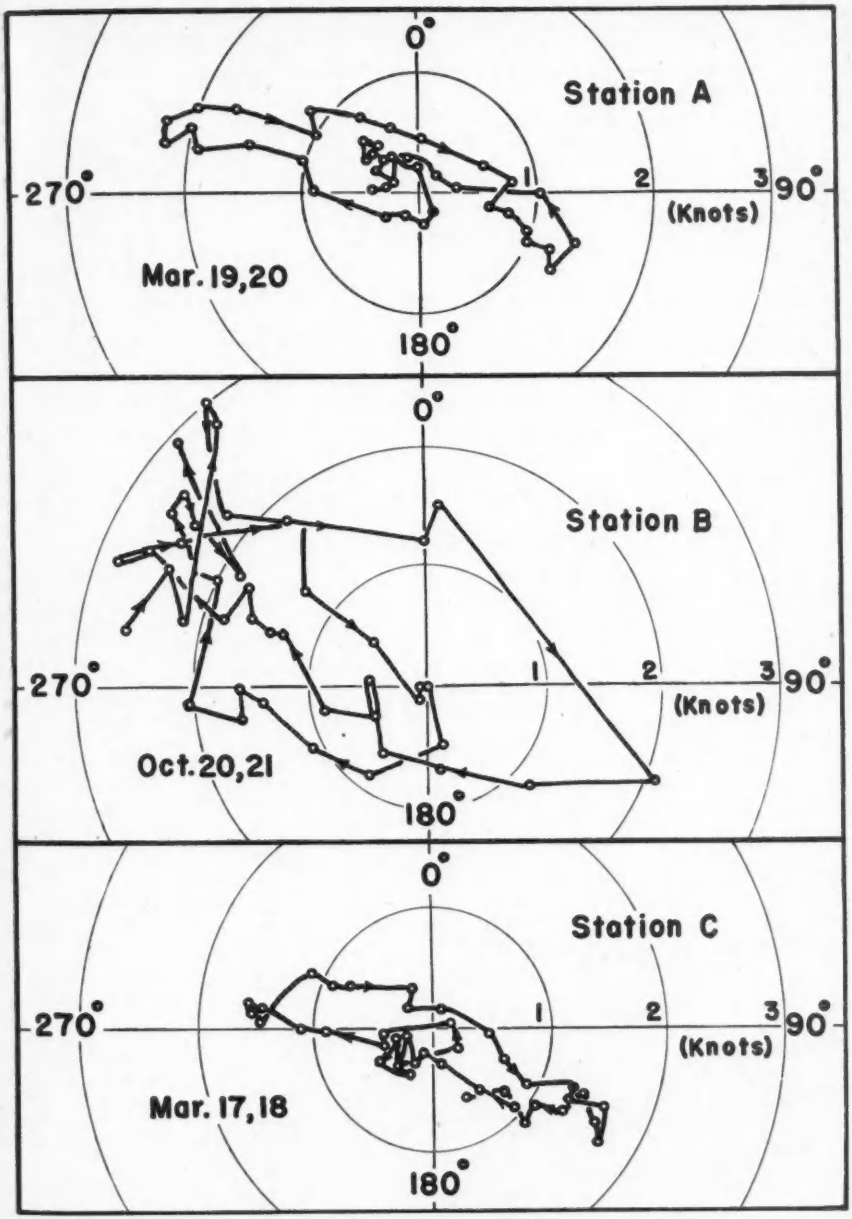

FIGURE 8. Hodographs of the tidal-current cycles at stations A, B and C in Juan de Fuca Strait, 1952. The velocity and direction are represented by the vector joining the centre to the appropriate point on the hodograph. The direction of rotation follows the arrows.

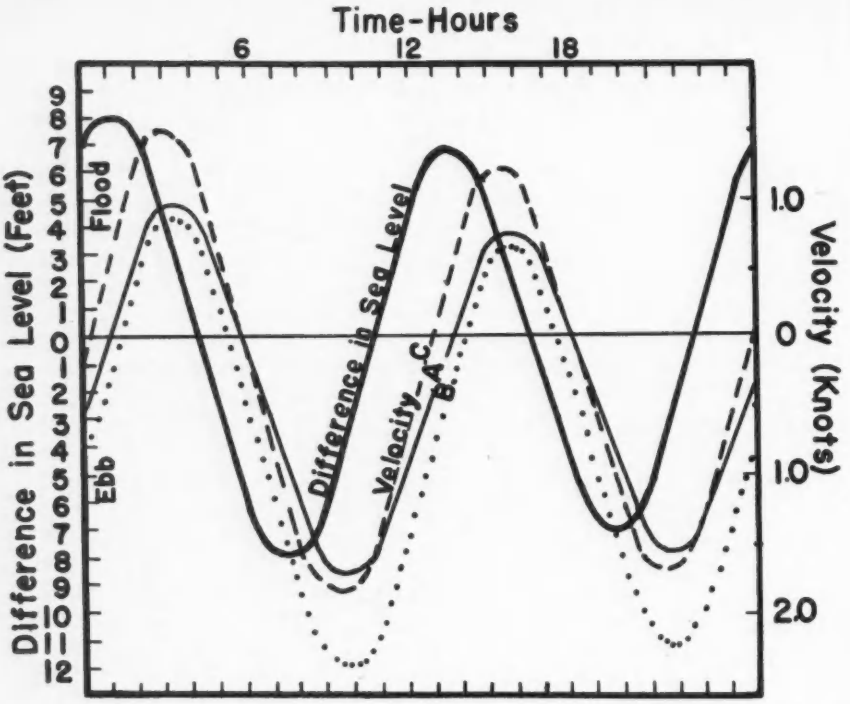

FIGURE 9. The cycle of the difference in sea level from Clayoquot to Point Atkinson, and the calculated tidal velocities.

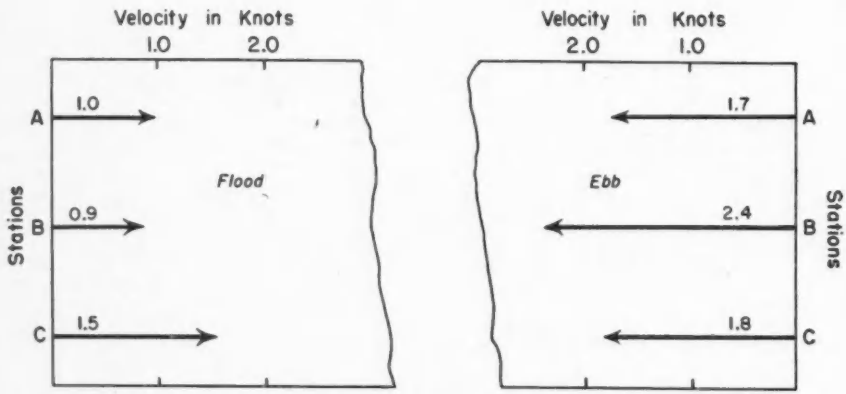

FIGURE 10. Vectors of the maxima of flood and ebb velocities at stations A, B and C in Juan de Fuca Strait when $\Delta H = \pm 8$ feet.

TABLE III. Calculated tidal currents at stations A, B and C in Juan de Fuca Strait (Figure 9).

Current stage	Station		
	A	B	C
Low-water slack			
Lag after zero tidal difference (*hours*)	2 : 50	3 : 20	2 : 10
Maximum Flood			
Lag after maximum (8 feet) tidal difference (*hours*)	2 : 20	2 : 10	2 : 00
Velocity (*knots*)	1.0	0.9	2.4
High Water Slack			
Lag after zero tidal difference (*hours*)	1:30	1:00	1:30
Maximum Ebb			
Lag after maximum (8 feet) tidal difference (*hours*)	2:20	2:10	2:00
Velocity (*knots*)	1.7	2.4	1.8

RULES FOR PREDICTING CURRENTS

Example: Determine the velocity and direction of the tidal current off Sheringham Point (Station A) at 14:30, June 15, 1953.

1. Note the time for which the current information is required. (i.e. 14:30)

   At station A subtract 2:20
   At station B subtract 2:10
   At station C subtract 2:00

   Example: Station A 14:30 — 2:20 = 12:10 (tidal time)

2. From the Tide Tables determine the time and height of the tides at Clayoquot and Point Atkinson that immediately precede and follow the tidal time.

   Example: June 15, 1953.

CLAYOQUOT		POINT ATKINSON	
time	*height*	*time*	*height*
9:06	1.7	06:30	11.9
15:37	10.3	13:41	2.7

3. Correct the heights to mean sea level (12).

   From Clayoquot subtract 7.2 feet
   From Point Atkinson subtract 10.0 feet

Example:

Clayoquot		Point Atkinson	
time	*height*	*time*	*height*
9:06	—5.5	06:30	1.9
15:37	3.1	13:41	—7.3

4. Plot these points on suitable time and height scales and complete the tide curve by the method outlined in the Hydrographic Manual (5). Example: (see Figure 11):

(*a*) Plot the time and height of the two points associated with Clayoquot tides.

(*b*) Join the points by a straight line (lightly).

(*c*) Divide this line into quarters.

(*d*) From the upper-quarter point measure vertically upwards 1/10 of the tidal range.

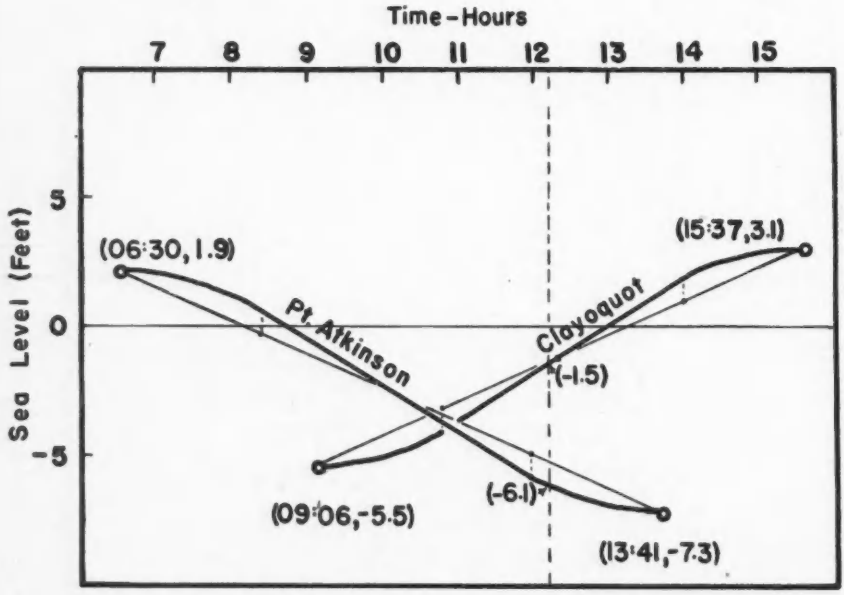

Figure 11. Example of the graphical calculation of the difference of sea level from Clayoquot to Point Atkinson.

(*e*) From the lower-quarter point measure vertically downwards 1/10 of the tidal range.

(*f*) Join these last two points (*d*) and (*e*) by a straight line.

(*g*) Join the ends of this line by a smooth curve to the high- and low-tide points.

(*h*) This tidal curve is accurate within 0.1 feet.

(*i*) Construct the similar curve for Point Atkinson tides.

5. Note the difference in height (ΔH) on the Clayoquot and Point Atkinson tide curves at the required time.

Example: At 12:10

Clayoquot height	−1.5
Point Atkinson	−6.1
Difference (ΔH)	+4.6

6. Set this difference (ΔH) in the appropriate equation.

Station A $V = 0.2\,\Delta H - 0.4$

Station B $V = 0.2\,\Delta H - 0.8$

Station C $V = 0.2\,\Delta H - 0.2$

Example: At Station A

$$V = (0.2) \times (4.6) - 0.4 = 0.5$$

7. A negative answer from Rule 6 signifies an ebb current.
A positive answer from Rule 6 signifies a flood current.

Example: At Station A

$V =$ Flood 0.5 knots.

Slack water occurs at station A when the sea level in Georgia Strait is 2.2 feet below the ocean. If it is lower the tide floods, and if higher it ebbs. At station B slack water occurs when the difference is 3.8 feet, and at station C when it is 0.9 feet.

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Annual Variations of Temperature and Salinity in the Bay of Fundy[1]

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INTRODUCTION

Observations of temperatures and salinities, on a monthly basis, in the Outer Quoddy Region (Figure 1) of the Bay of Fundy since 1924, have provided a means of following the hydrographic conditions of the Bay of Fundy. These observations are taken about the middle of each month at Prince Station 5 (Lat. 44°56′48″N.) (Long. 66°48′41″W.).

Data from Station 5 have been used by several authors to illustrate the annual temperature cycle in relation to their specific investigations. Hachey (1934) determined replacements of the waters of the Bay of Fundy through variations in temperature at Station 5, and used these data as well to show the annual cycles of temperatures and salinities during his general survey of the hydrographic conditions in the Bay of Fundy in 1929 and 1930 (Hachey and Bailey, 1952). A similar procedure was used by Watson (1935) in dealing with the mixing and residual currents in the Bay of Fundy. Up to the present time, there have been no attempts to use this large body of data to establish mean values and to study variations that have occurred over the period 1924–52.

SOME FEATURES OF THE WATERS OF THE BAY OF FUNDY

It has been generally agreed by previous investigators that the circulation in the main portion of the Bay of Fundy is in an anticlockwise direction (Figure 1), and that inflowing waters from the open ocean hold close to the Nova Scotia coast, while outflowing waters hold to the Grand Manan side of the Bay. In Grand Manan Channel, Mavor (1922) found northward residual currents, whereas MacGregor and McLellan (1952) estimated the residual currents to be southward. Both Watson (1936) and McLellan (1951) suggest that residual currents in the Grand Manan Channel are determined chiefly by the winds. On the basis of the varying nature of the residual flow in Grand Manan Channel, it would appear that outflowing waters from the Bay of Fundy hold generally to the eastern rather than to the western side of Grand Manan.

As the waters are carried into the bay a progressive mixing takes place, with the result that the waters at the head of the bay are found to be thoroughly mixed. Mixing on a considerable scale takes place in an area to the southwest of Grand Manan, and also over an area extending along the northwestern coast of Nova Scotia (Hachey and Bailey, 1952).

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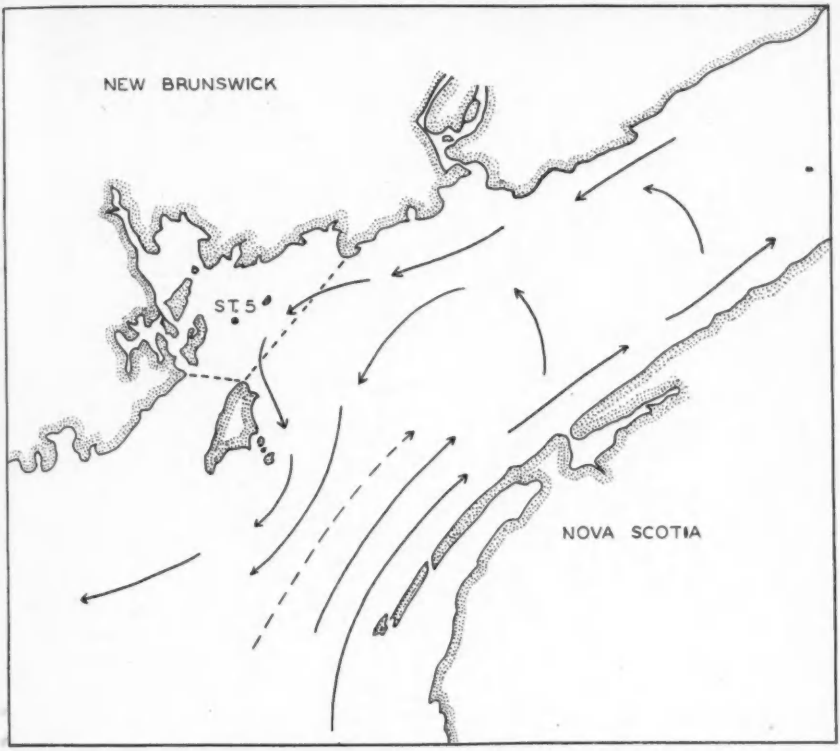

FIGURE 1. Map of Fundy delineating the Quoddy Region and illustrating the general circulation of the area.

The principal drainage system supplying fresh water to the Bay of Fundy is that of the Saint John River and the resultant outflow is influenced to a considerable extent by these waters, which can be readily traced, at times of freshets, as far as Grand Manan (Watson, 1936; Hachey and Bailey, 1952).

Large tides are features of the area with amplitude even greater than 53 feet at the head of the bay (Tide Tables, 1952). Tidal action together with the physical features of the bay are responsible for intense mixing of the waters, with the result that changing hydrographic conditions in the bay as a whole may be observed at a suitably chosen location. Prince Station 5 has proven to be an excellent location, readily accessible for observing and recording the prevailing hydrographic conditions.

PROCEDURE OF ANALYSIS

In analysing the water column at Station 5, it is convenient to deal with a surface layer, extending to a depth of 25 metres, an intermediate layer lying

between the 25- and 75-metre levels, and a bottom layer between 75 and 90 metres. Because of the small vertical gradients of temperature and salinity in each layer, the original data can be treated by a weighted-mean method to obtain representative values of temperature and salinity for each layer.

On the basis of the temperature data for the period 1932–51, representative values were obtained by use of the following equations:

1. For the surface layer: $T_S = \frac{1}{10}(2T_0 + 5T_{10} + 3T_{25})$
2. For the intermediate layer: $T_I = \frac{T_{25} + 2T_{50} + T_{75}}{4}$
3. For the bottom layer: $T_B = \frac{1}{2}(T_{75} + T_{90})$

where T_0, T_{10}, T_{25}, . . . are the observed temperatures at depths of 0, 10, 25 metres, etc. Corresponding values for the salinity in each layer were determined in the same manner. The resulting values were then treated as actual observations, and monthly mean and annual mean temperatures and salinities were determined for each layer.

NORMAL MEAN MONTHLY TEMPERATURES

Normal mean monthly temperatures (normals) for the three layers at Station 5 are illustrated in Figures 2–4. The dashed lines outline the limits of temperature values attained, and the year is indicated if the temperature differs from the normal by more than 0.5°C. As may be seen from the diagrams, the normal curves are all sinusoidal in form, but each is distinctly different, each having a different phase and a different amplitude. The salient features of each normal curve are presented in Table I.

An interesting fact regarding the three curves is that the maxima occur approximately two weeks later in successive layers. Since the warming of the deeper waters is carried out almost wholly by vertical mixing, this time-lag is a measure of the efficiency of the tidal mixing in the area. In the case of the minima, on the other hand, autumnal and winter cooling reduces the stability of the upper layers so that more efficient mixing takes place, and the time-lag is practically zero.

NORMAL MEAN MONTHLY SALINITIES

The curves for the normal salinities in each layer are shown in Figures 5–7 with the limits described by dashed lines. The normal salinity curves are in most aspects similar to the curves for the normal temperatures, but comparatively large divergences from true sinusoidal curves are in evidence.

The values presented in Table II show that in spite of intense tidal mixing a small salinity gradient persists. It may also be observed that the maximum salinity in the surface layer normally occurs a week later than in the bottom layer, while the minimum salinity in the surface layer normally occurs nearly two weeks earlier than in the bottom layer.

TEMPERATURE AND SALINITY ANOMALIES

In dealing with the normal mean monthly temperatures it is readily apparent from the rough data that there exisit years or groups of years in which the temperatures are several degrees above or below normal. Hachey and McLellan

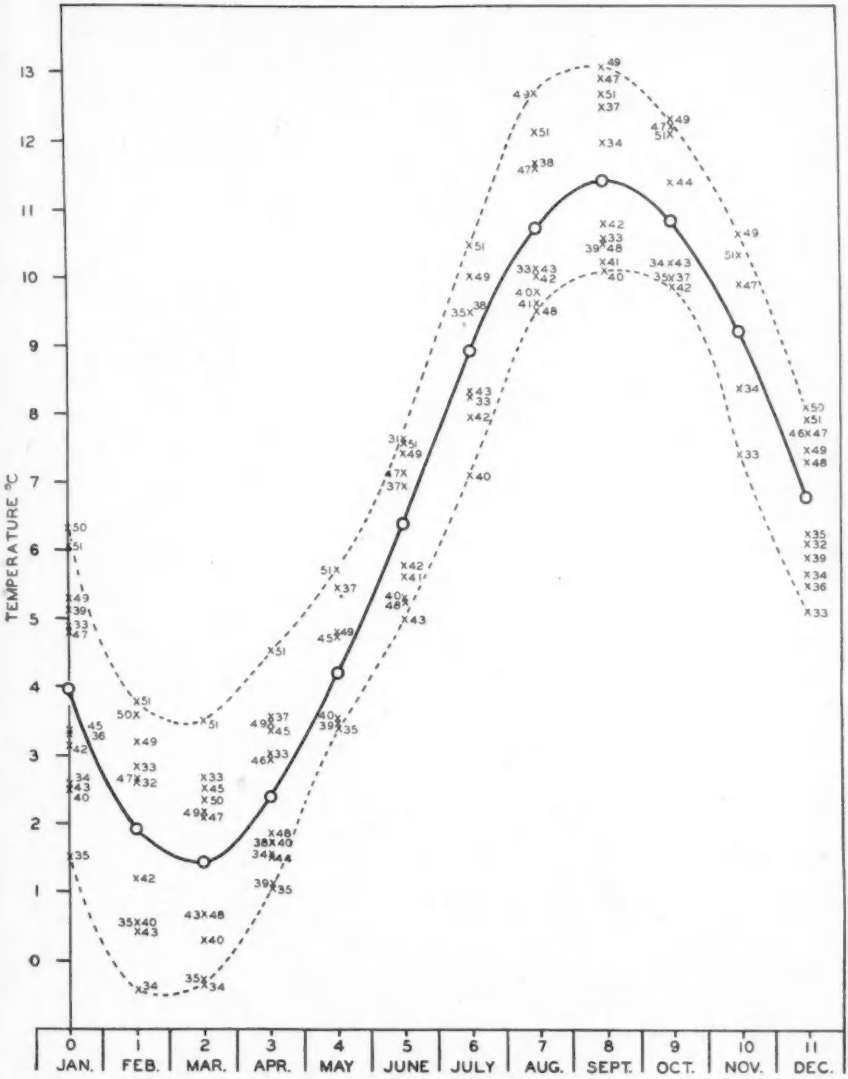

FIGURE 2. Normal mean monthly temperatures for the surface layer at station 5.

(1948) dealt with similar observed anomalies in the sea temperatures at St. Andrews, and pointed out some general interesting correlations. These anomalistic years were termed "warm" and "cold" years. The departure from normal temperatures and salinities at Station 5 for a "cold" year (1935) and a "warm" year (1951), are shown in Figures 8 and 9.

The "warm" and "cold" years show a very definite displacement from the

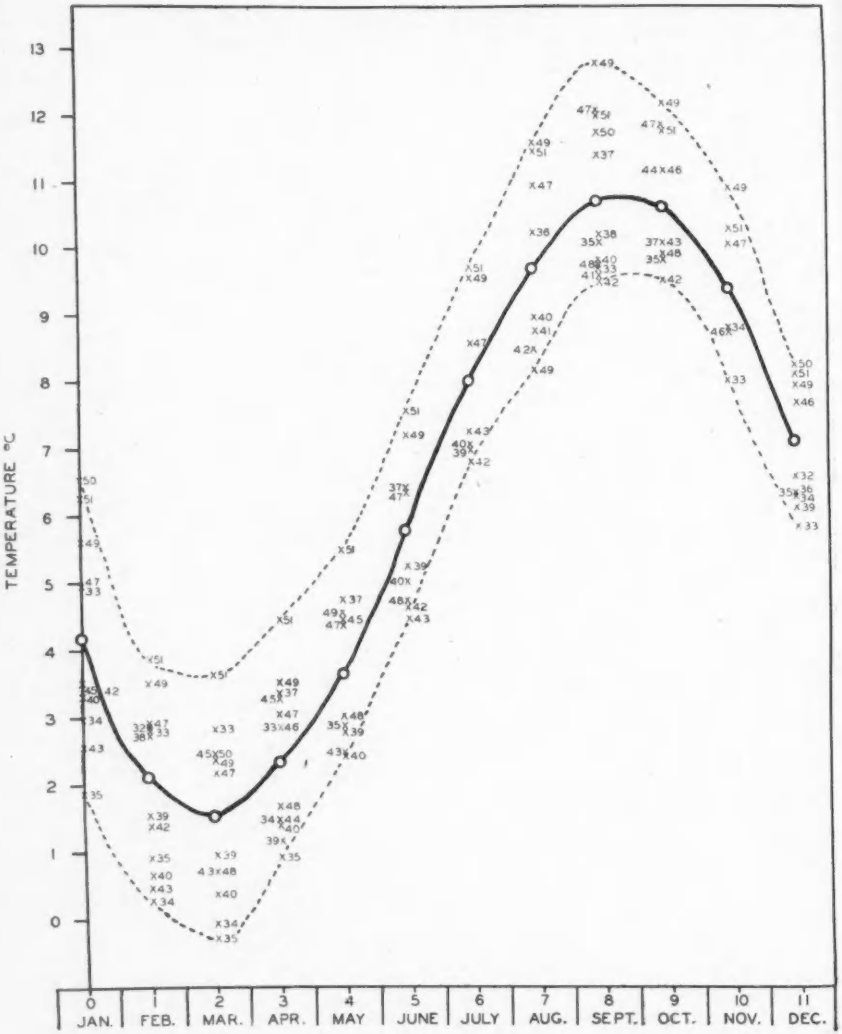

FIGURE 3. Normal mean monthly temperatures for the intermediate layer at station 5.

normal temperatures, the "warm" years being displaced somewhat more than the "cold" years. In reality these anomalistic temperatures should not be linked too closely with the period of a year. Over the period of observation, temperatures have been observed to remain above normal for a period of two years, as at the present time, and for short periods of only two or three months. It is also to be

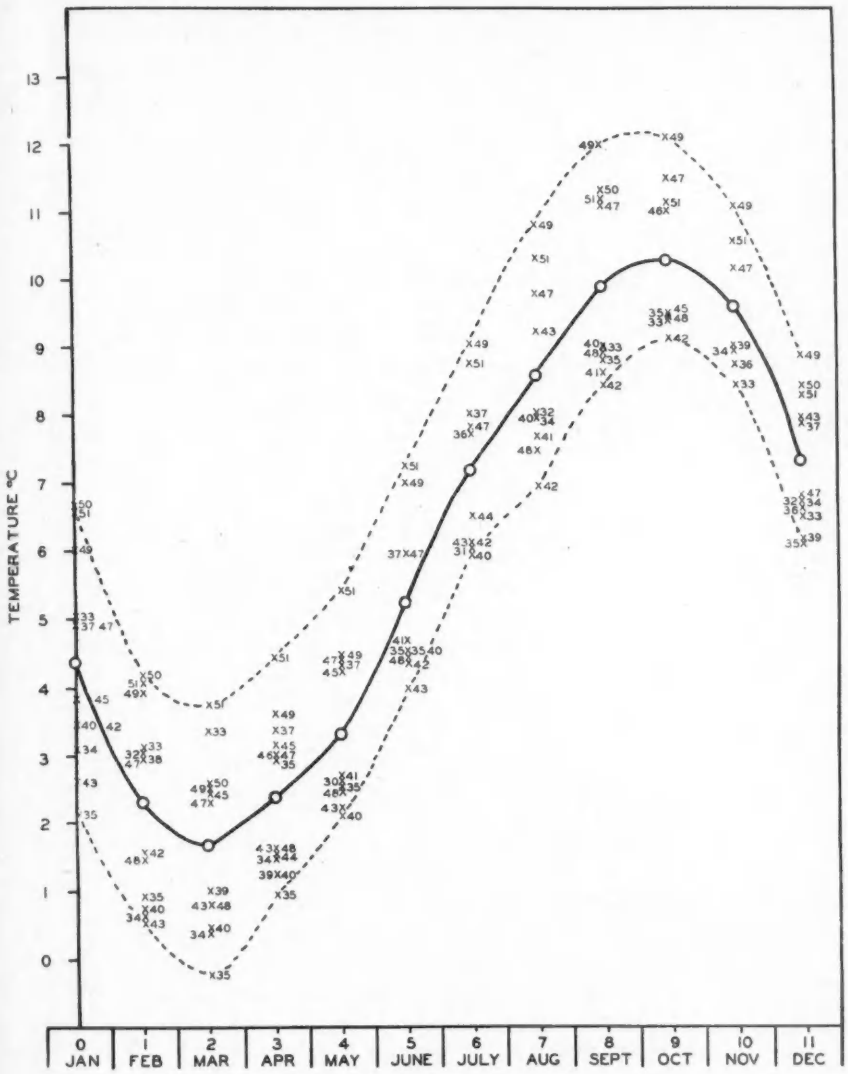

FIGURE 4. Normal mean monthly temperatures for the bottom layer at station 5.

TABLE I. Important features of the normal mean monthly temperature curves in the three layers at Station 5.

	Max.	Date	Min.	Date	Annual mean
Surface layer	11.44°C.	15 Sept.	1.47°C.	15 Mar.	6.51°C.
Intermediate layer	10.74	30 Sept.	1.54	15 Mar.	6.29
Bottom layer	10.26	15 Oct.	1.67	15 Mar.	6.01

TABLE II. Important features of the normal mean monthly salinity curves in the three layers at Station 5

	Max.	Date	Min.	Date	Annual mean
Surface layer	32.49‰	22 Oct.	31.08‰	15 May	31.92‰
Intermediate layer	32.63	18 Oct.	31.55	21 May	32.12
Bottom layer	32.82	15 Oct.	31.89	28 May	32.34

borne in mind that these anomalistic periods may develop at any time throughout the year, rather than the first of the calendar year. The departures from normal salinities, in general, seem to fall at random about the normal, and seem to bear little relation to "cold" and "warm" years. In Figure 9, the salinities for 1935, a "cold" year, conform closely to normal values. The salinities for 1951, a "warm" year, deviate considerably from the normal and are comparatively lower than normal salinities.

T-S RELATIONSHIPS

The normal T-S curves for each layer are produced in Figure 10 by plotting the normal temperatures and salinities for each month and joining the points relative to each layer. The T-S cycle is thus illustrated for each layer. Many important features about the normal conditions of the waters in the bay may be studied from this type of diagram. σ_t lines are plotted on the diagram so that densities of the water column may be readily determined.

The entire cycle of the hydrographic conditions at Station 5 is clearly defined by the T-S diagram. The normal values of temperature and salinity are illustrated, as well as the normal annual ranges. It must be remembered that these are normal conditions that are described, and that considerable deviations may occur in any particular year.

Between the middle of February and the middle of March, there is normally a short period when the water column at Station 5 is nearly homogeneous with respect to temperature and salinity. The surface layer continues to cool while the bottom layer begins to warm. Until April-May, with the land drainage at a maximum, the salinity in each layer becomes progressively fresher, with the greatest changes taking place in the surface layer. By the middle of April the waters are isothermal but show a considerable difference in salinity. In May the minimum salinities are reached in all layers while the temperatures are increasing. During the summer months both the temperatures and salinities increase in value. In the bottom layer an increase of salinity in August causes a

very noticeable change in the trend of the T-S cycle. This would seem to be related to a phenomenon of replacements of Bay of Fundy waters which is being dealt with in a later report. Undoubtedly, a steady replacement is involved during the time of "spring freshets", but vertical mixing on a large scale almost completely masks the possible increases in salinity that such replacements might entail. It is not until the middle of the summer when the river discharges are at a minimum that replacements can be readily detected. By the middle of

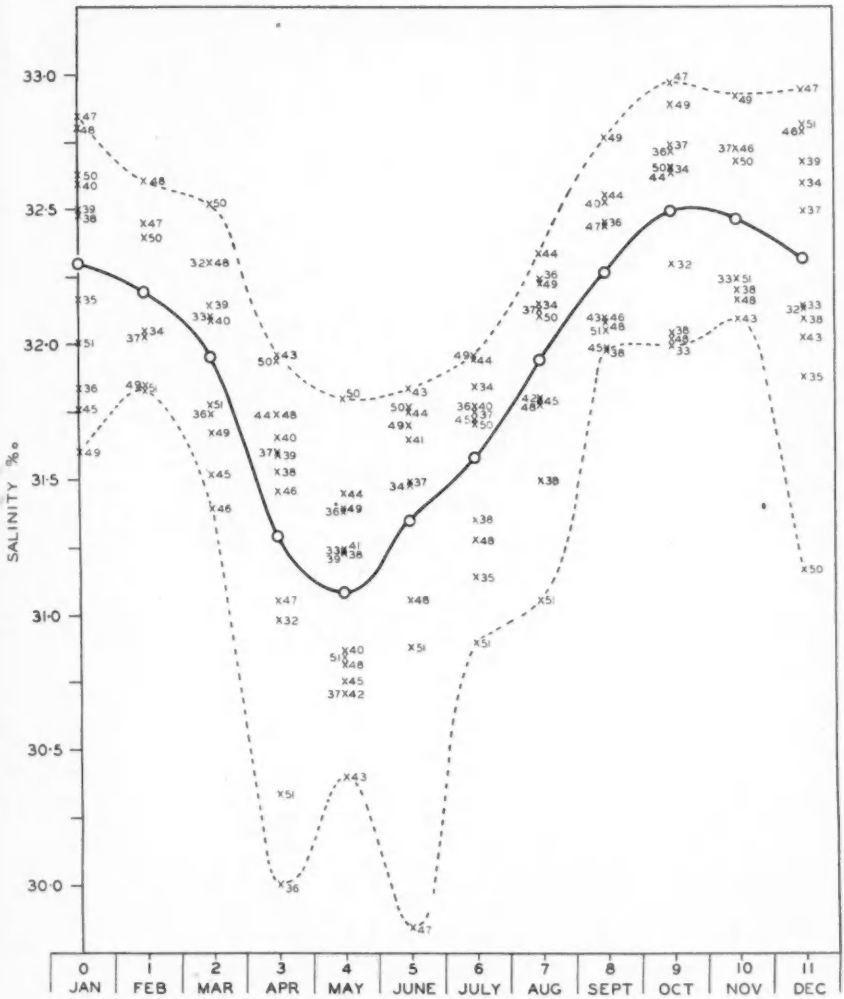

FIGURE 5. Normal mean monthly salinities for the surface layer at station 5.

September the temperature has reached a maximum in the surface layer, and the salinities have increased in all layers. The maximum temperature of the surface layer is reached in late September, and by the end of the month all layers have reached their highest salinities. Temperatures and salinities decrease at a comparatively steady rate in all layers until February, when the waters have nearly the same characteristics from top to bottom.

In summarizing the cycles of the T-S characteristics, it is obvious that the stability of the water column reaches two maxima, one in May due to freshening of the surface layer, and one in August due to an increase in salinity in the bottom layer. A time is reached in late February or early March when the stability of the water column is zero. It is also of interest to note that temperatures in the bottom layer are greater than in the surface layer from November until April.

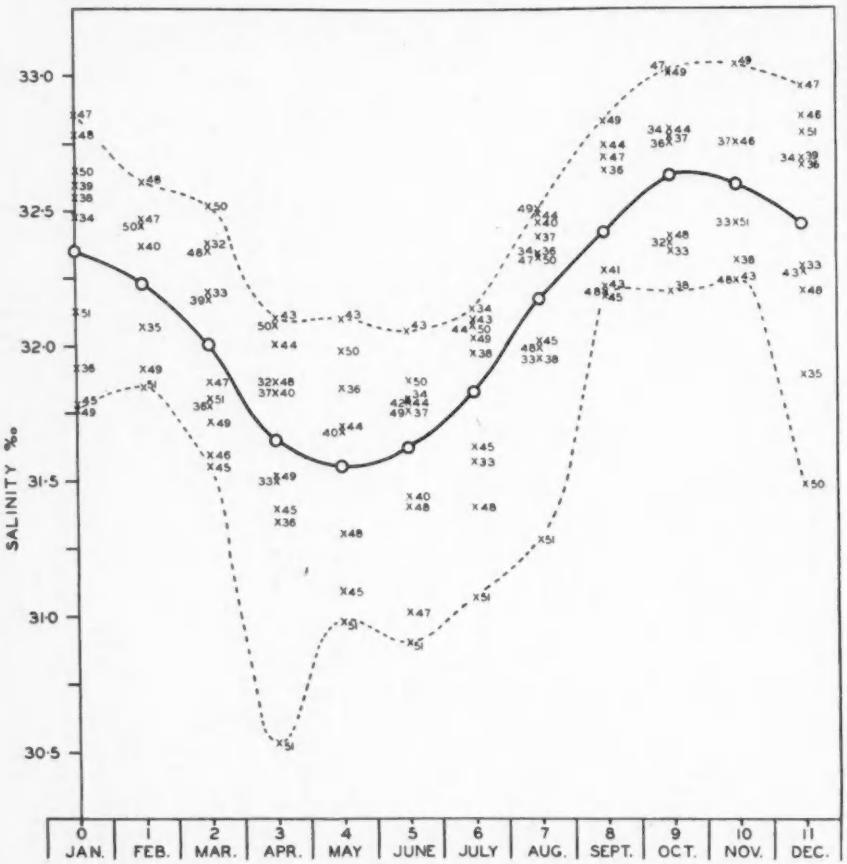

FIGURE 6. Normal mean monthly salinities for the intermediate layer at station 5.

EQUATIONS FOR NORMAL CURVES

On the basis that the normal curves of temperatures are sinusoidal, the equations would be of the form:

$$y = A - B \sin \frac{2\pi}{t} (x + \epsilon)$$

where y is the normal monthly mean temperature in degrees Centigrade

A is the mean annual temperature

B is one-half of the annual amplitude

t is the period of 12 months

x is the time in months

ϵ is the phase or lag in months.

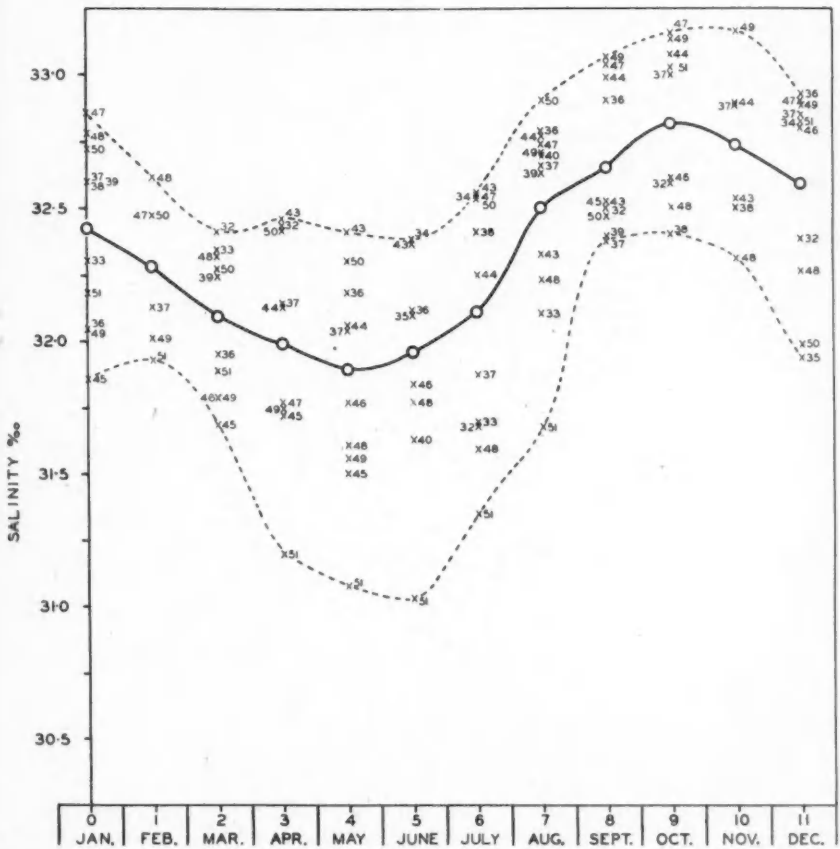

FIGURE 7. Normal mean monthly salinities for the bottom layer at station 5.

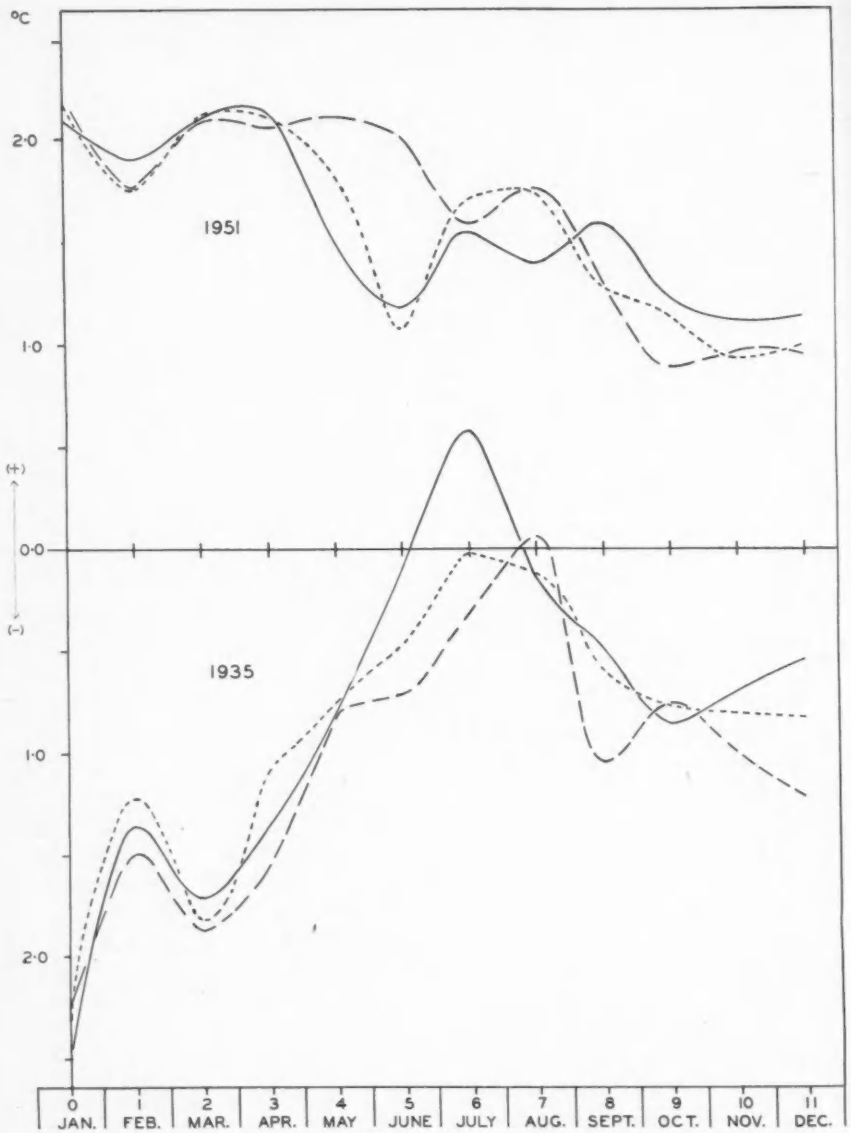

FIGURE 8. Deviations of temperatures from the normal in the surface (——), intermediate (– – – –), and bottom (— —) layers for a "cold" year (1935), and a "warm" year (1951).

The theoretical curves for the normal theoretical temperatures are shown in Figure 11, with the normal temperatures indicated.

Using the general equation to determine the particular equations for temperatures, at Station 5, we obtain the following:

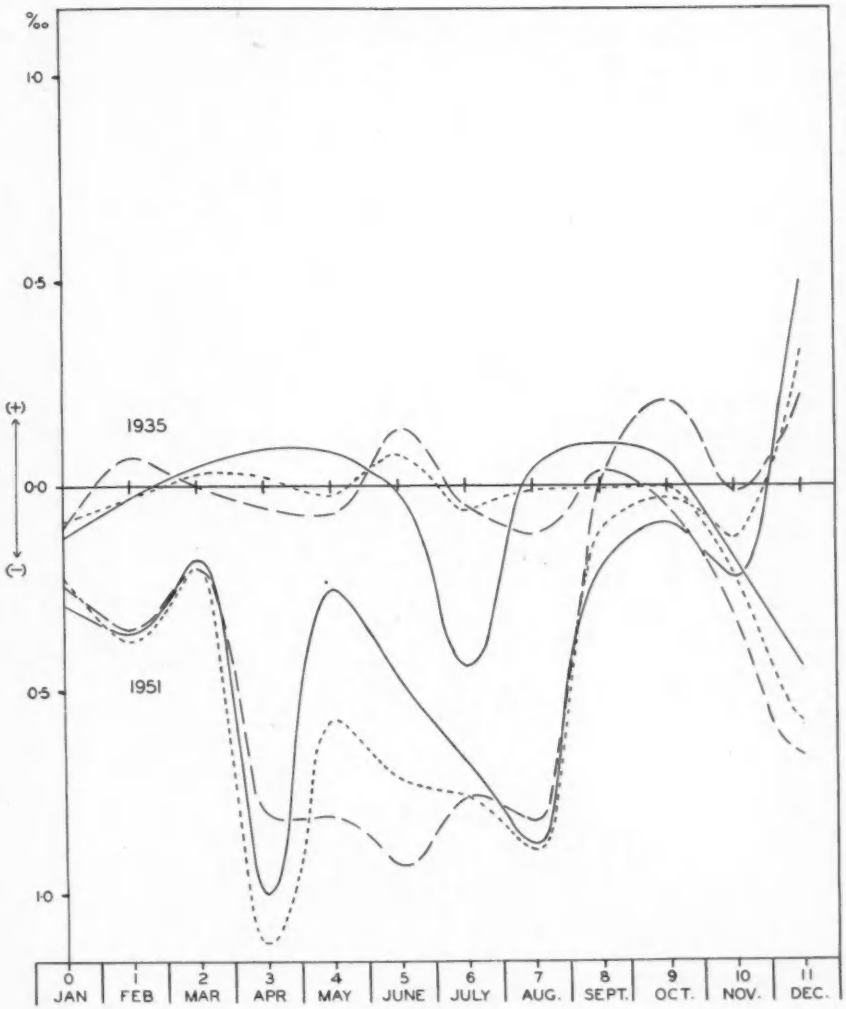

FIGURE 9. Deviations of salinities from the normal in the surface (——), intermediate (– – – –), and bottom (— —) layers for a "cold" year (1935), and a "warm" year (1951).

Station 5 Normal Monthly Mean Temperatures

(*a*) Surface layer: $y = 6.5 - 5.0 \sin \frac{\pi}{6} (x + 1.0)$

(*b*) Intermediate layer: $y = 6.3 - 4.6 \sin \frac{\pi}{6} (x + 0.7)$

(*c*) Bottom layer: $y = 6.0 - 4.3 \sin \frac{\pi}{6} (x + 0.6)$

From the plotted results it is readily seen that the equations represent the water temperatures extremely well.

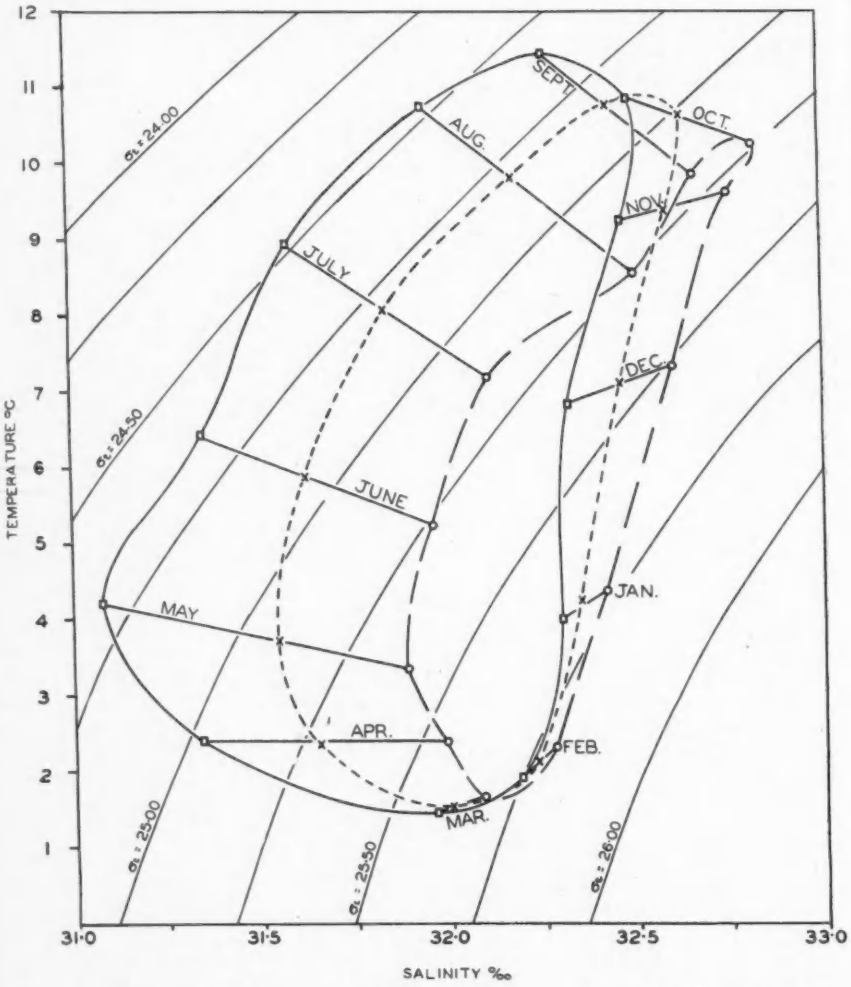

FIGURE 10. Normal T–S curves for each month, and the normal annual T–S cycle for the surface (——), intermediate (– – – –), and bottom (— — —) layers.

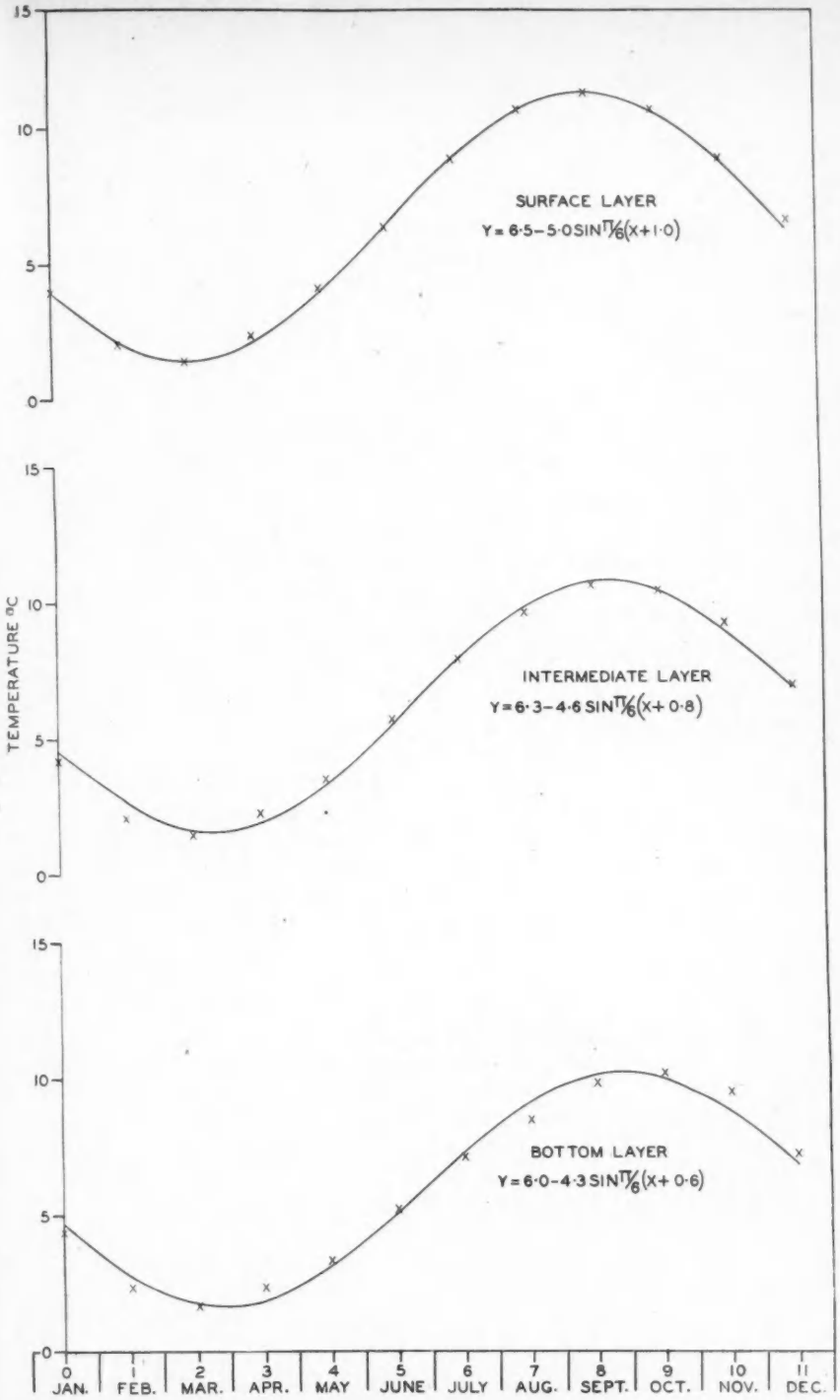

FIGURE 11. Normal theoretical temperature-time curves for the surface, intermediate, and bottom layers at station 5.

DISCUSSION

It is to be expected that surface water temperatures, on the average, would follow a simple sinusoidal curve, and where vertical mixing is prominent, it is also expected that the deeper temperatures would follow similar curves. The annual change in salinity in the Bay of Fundy is of a cyclic nature, in that salinities vary from a minimum to a maximum and thence to a minimum within a twelve month period (Figures 5–7). It can be shown that normal salinities of the bottom layer can be well represented by the equation:

$$y = 32.34 - 0.47 \sin \tfrac{\pi}{6}(x + 5.4),$$

where y is the salinity and x the time in months. It then follows that density changes will also be cyclic in character. With these points in mind, the T-S diagram in Figure 10 is of further interest. Normally the density of the bottom layer is greatest in January or February, having a value of approximately 25.75, when the temperature, salinity, and density of the water column are practically uniform. A decrease in density in all layers takes place between February and July, the rate of change being greatest in the surface layer and in the months March to May, when temperatures are increasing rapidly and salinities are decreasing. From July to September, the density in the various layers undergoes little change except for the bottom layer in August. This August change in density is but the forerunner of very sharp changes in density that take place in all layers between September and January when salinities undergo little change in comparison to the temperature changes. The temperature changes are chiefly due to cooling *in situ*, modified by the upwelling of deeper and warmer waters. As a result there is a period when the Archimedian forces within the water body are under rapid change, and either these rapid changes must be offset by corresponding changes in the outer ocean waters or there must be replacement of waters to bring about necessary adjustment of the internal forces. Irrespective of the very important effect of winds on replacement and internal adjustments in a water mass, we can appreciate two different types of replacement of Bay of Fundy waters: (*a*) the "draw-in" of outside waters to replace that used in mixing with land drainage, chiefly during the months when the land drainage is large; (*b*) the large-scale replacements, which sometimes might be required for adjustments of the internal forces in the sea, and which take place during the later months of the year when rapid density changes are taking place.

Both types have been observed, the former being already dealt with in some detail (Hachey, 1934), the second to be dealt with in a report to follow. An external force such as wind stress has a very pronounced effect on the time and method of replacement.

SUMMARY

1. Normal water temperatures and salinities, for Station 5, representative of the Bay of Fundy have been determined for three different layers, based on twenty years of observation.

2. The plotted normal water temperatures in relation to time are sinusoidal curves for all depths.

3. The plotted normal salinities for the greater depths in relation to time approximate sinusoidal curves.

4. The normal annual range of temperature is 10°C. for the surface layer and 8.6°C. for the bottom layer. "Warm" years exhibit monthly temperatures which may be two degrees above normal, while "cold" years have monthly temperatures as much as two degrees below normal.

5. The normal annual range of salinity is from 31.1‰ to 32.5‰ for the surface layer, and from 31.9‰ to 32.8‰ for the bottom layer. In 1951, a "warm" year, the salinities were more than 1.0‰ below normal.

6. The stability of the water column reaches two maxima, one in May and one in August. In late winter, the stability of the water column is zero.

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Tidal Current Observations in Hecate Strait[1]

By Bruce S. Mackay[2]
Pacific Oceanographic Group

ABSTRACT

Five short series of surface and bottom current measurements were made at one position in Hecate Strait during July 1952. The surface currents were dextro-rotary, while the bottom currents were laevo-rotary and the dominant flows were parallel to the nearby coast-line. At the surface there was evidence of a steady southerly flow of about one-third knot.

INTRODUCTION

Previous studies in Hecate Strait have been confined to scattered surface-current measurements by hydrographic vessels and some general observations of the stronger currents in the region that affect navigation. These few observations are recorded on the Canadian and Admiralty charts and in the British Columbia Pilot.

The location and principal geographic features of Hecate Strait are shown in Figure 1. Approaching the region from the south, the bottom gradually shoals from about 100 fathoms to from 10 to 50 fathoms off the north end of the Queen Charlotte Islands. From there the bottom falls away in Dixon Entrance to a depth generally exceeding 100 fathoms.

The principal feature of the bottom topography of northern Hecate Strait is the shallow-water bank (less than 20 fathoms) extending 15 to 20 miles east from Graham Island and 60 miles south from Dixon Entrance. Between this bank and the eastern shore are two trenches from 50 to 60 fathoms deep, separated by a relatively shallow ridge. The current measurements were made, as shown in the figure, at a position on the eastern edge of this ridge and may be considerably affected by the surrounding bottom topography.

The tidal rise in northern Hecate Strait is marked by considerable diurnal inequality at low water and a range of more than 20 feet during spring tides. Previous observations indicate that throughout most of Hecate Strait the flood sets northward and the ebb southward in a simple reversing tidal system, while in northern Hecate Strait there is a region of confused rotary tidal currents. The configuration of the tidal streams which might account for such a system have not been solved, but a consideration of the geography of the region indicates that the configuration may be complex.

During the summer the winds in Hecate Strait are generally from the northwest and less than 20 miles per hour. During the remainder of the year the winds are dominantly from the southeast and of variable strength.

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CURRENT MEASUREMENTS

The current measurements were made from H.M.C.S. *Cedarwood* during periods of light winds, when the ship could anchor without rolling excessively. During the survey there were only five such periods (Table I) ranging in length from 5 to 40 hours, and of these, only two cover a complete tidal cycle and permit an analysis to determine the tidal and non-tidal flow.

Surface currents were measured every half hour with a current pole and log line (1). This apparatus consists of a 16-foot pole weighted at one end, to float upright in the water with about one foot showing above the surface. As it drifts away from the anchored ship it carries a light line marked at suitable

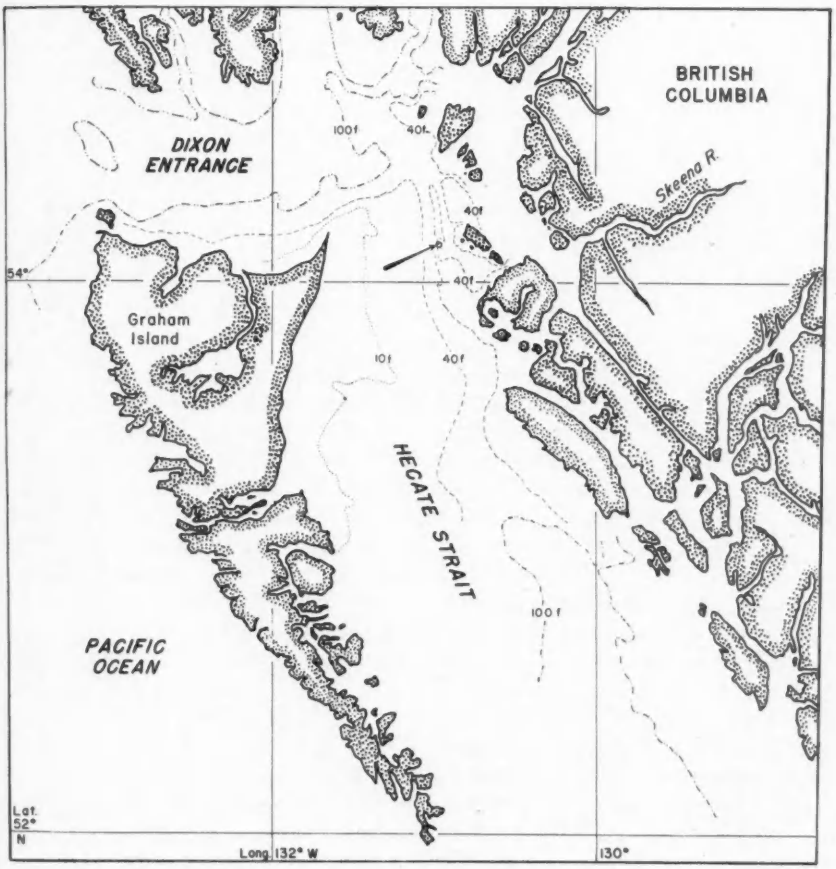

FIGURE 1. Chart of Hecate Strait and surrounding region showing the location of the anchor station.

intervals. The direction of the pole's drift is noted, and the time for a number of marks to "run out" is a measure of the current velocity.

The errors involved in current-pole measurements are from "sail effect" due to the wind on the pole, stretching of the log line and irregularities in the paying out of the log line (especially during rough weather). These do not amount to more than 0.2 knot.

Bottom currents were also measured half-hourly at 40 fathoms depth using a standard Ekman propeller-type current meter (2). No correction of the observations for the effect of ship's roll has been attempted. However, the discussion of the results has been restricted to Series III and IV, made when the ship's roll was slight or non-existent. Under these conditions the observational errors are considered negligible.

TABLE I. Summary of observations.

Series	Date 1952	Duration (*hours*)	No. of surface current observations	No. of bottom current observations
I	July 12–13	22	Nil	43
II	July 18	5	9	Nil
III	July 20–21	27	51	53
IV	July 24–26	41	80	86
V	July 26–27	9	18	38

DATA

SURFACE CURRENTS

The character of the surface currents is shown in Figures 2 and 4. The current direction rotates continually in a clockwise manner with an approximately semi-diurnal period. Accompanying this rotation is a pronounced cyclic variation in current speed, also with an approximately semi-diurnal period. Since these periods are alike and also similar to the period of tidal rise, a nearly constant phase relation exists between the current speed, current direction, and tidal rise.

The salient features of this relation are evident from a comparison of the curves in Figure 2. At the time of low tide the current is a minimum and is directed nearly northward. As the tide rises the current increases in strength and changes direction in a clockwise manner until at high tide the current reaches its maximum speed and is directed nearly southward. As the tide falls, the current decreases in strength, and changes direction until at low tide it is again a minimum and directed northward.

Marmer (3) has shown that such surface currents can be analysed into rotary tidal currents and steady currents. The steady currents are determined by summing algebraically over a tidal cycle, the observed hourly values of the currents after they have been resolved into north-south and east-west components, and deriving the mean. Steady currents calculated in this way from Series III and IV are found to be 0.4 knot bearing 210° and 0.3 knot bearing 190° respectively.

Rotary tidal-current speeds and directions have been calculated at the surface from Series III and IV by subtracting vectorially the steady currents from the observed currents. The results have been plotted as functions of time and are shown in Figure 3 for comparison with the observed currents. These tidal currents still exhibit a cyclic variation in speed, but the range is less pronounced, and during Series IV the period of variation was shorter and more irregular than

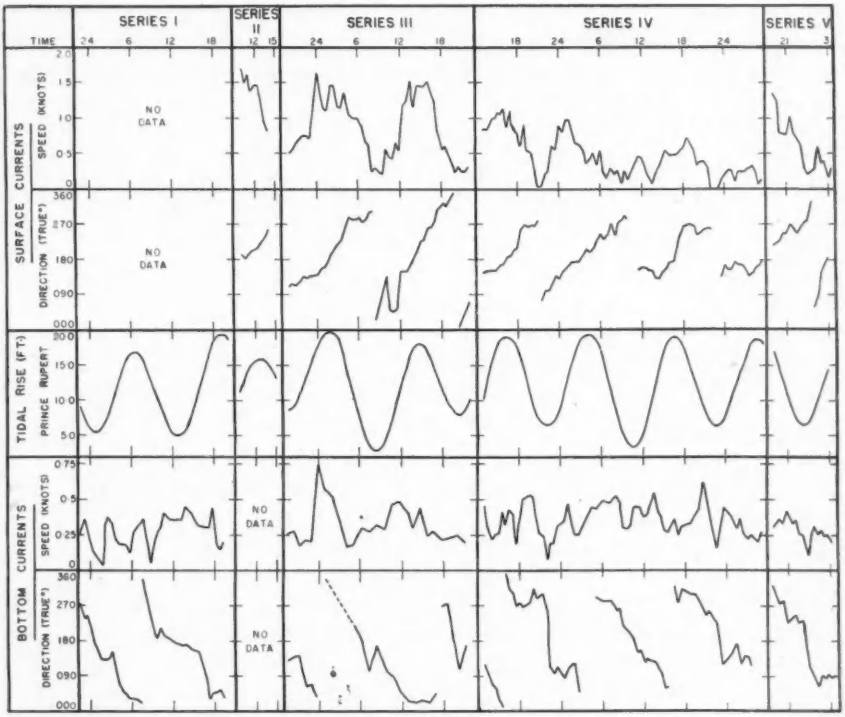

FIGURE 2. Surface-current speeds and directions, bottom-current speeds and directions, and the tidal rise at Prince Rupert, during five series observed in July 1952. (Times are P.D.S.T.)

that of the observed currents. The elimination of the steady current has also removed some of the irregularities in the rotation and made it more uniform throughout the tidal cycle.

The maximum calculated tidal currents during Series III and IV are 1.25 knots and 0.9 knot respectively. Since Series III occurred at the time of spring tides, the 1.25-knot current probably represents one of the largest tidal velocities during the year at the point of observation. The decrease in velocity between

Series III and IV can be associated with the progression from spring to neap tides.

Bottom Currents

The speeds and directions of the observed currents at a depth of 41½ fathoms are shown in Figures 2 and 5. These currents, like the surface currents, rotate with a semi-diurnal period. The direction of rotation, however, is counterclock-

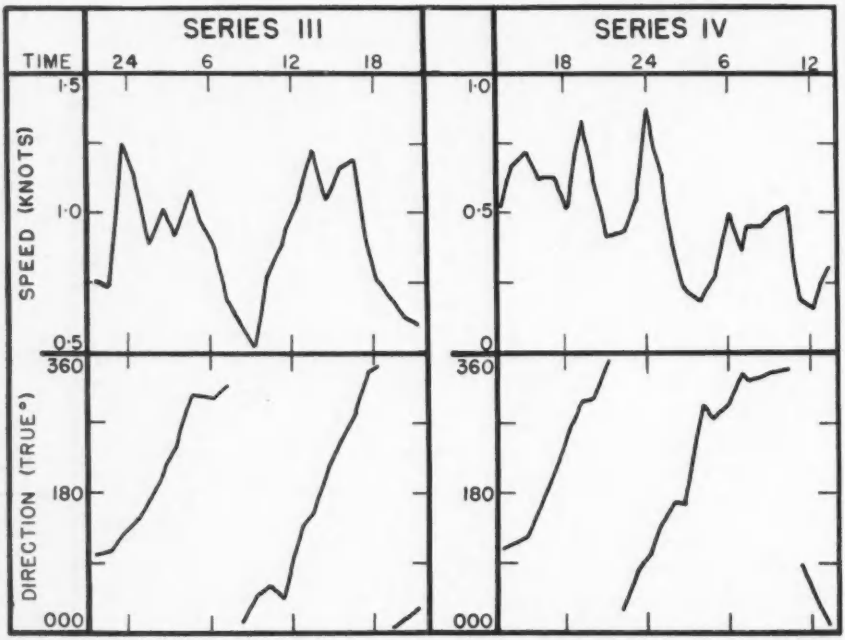

Figure 3. Series III and IV surface-current speeds and directions with the steady flow eliminated.

wise, opposite to the surface currents. The implications of this opposite rotation are that the direction of flow of the bottom currents with respect to the surface currents changes continuously during the period of rotation. Thus, at high and low water, when the bottom currents are directed north and south respectively, the surface currents are directed oppositely, while at approximately half-way between high and low water the bottom and surface currents flow in the same direction.

The variations in speed accompanying the rotation are not as pronounced as those of the surface currents, with the result that the phase relation between the tidal rise and the current speed is not clearly defined. It appears from Figure 2 that the minimum speeds occur at approximately high and low water

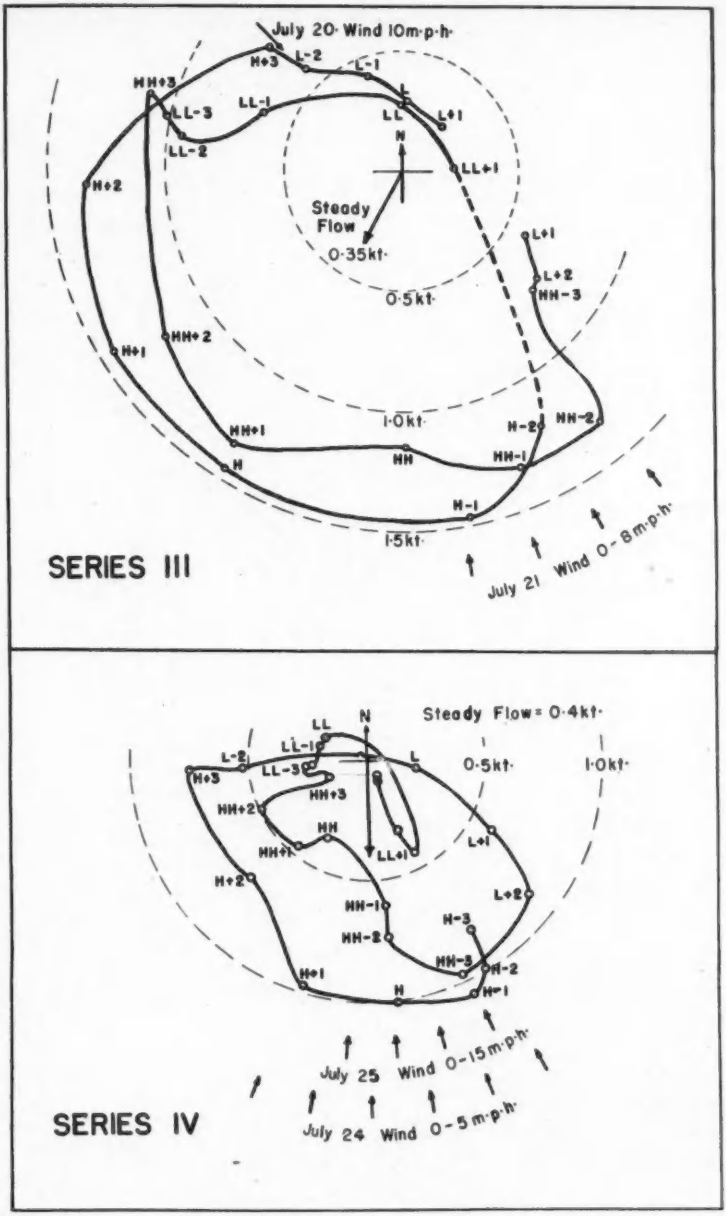

FIGURE 4. Series III and IV surface-current hodographs. Wind vectors during the period of observation and on the day preceding the observations are also shown.

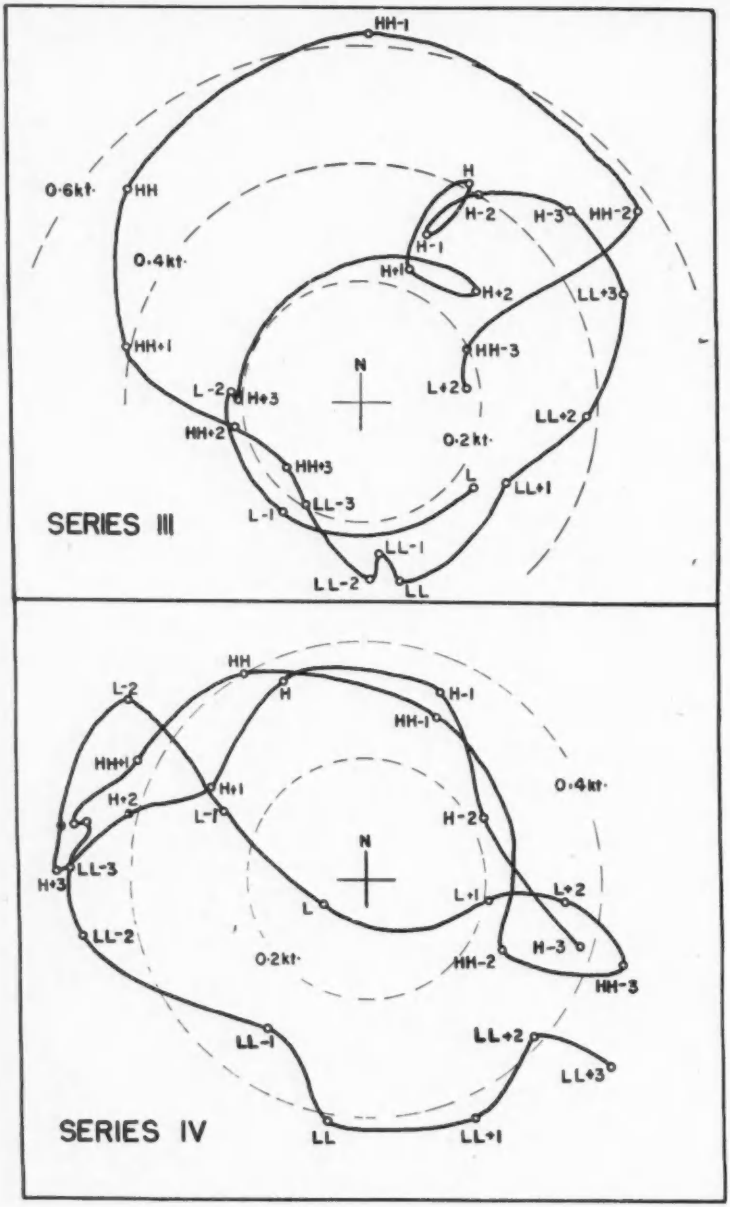

FIGURE 5. Series III and IV bottom-current hodographs.

and the maximum speeds about half-way between high and low water—indicating a period of about six hours or approximately half the period of rotation.

The occurrence of two maximum and minimum speeds during the period of rotation, rather than one as in the surface currents, indicates the existence of rotary tidal currents uncomplicated to any extent by accompanying steady currents (1, 3). This observation has been verified by calculating the steady current speeds near the bottom from Series III and IV. In both cases the speed was less than 0.1 knot and therefore not large enough to obscure the form of the rotary currents.

DISCUSSION

An examination of the wind vectors shown on the surface current hodographs (Figure 4) indicates that on no occasion during the periods of observation was the local wind directed so as to produce the observed steady southerly flow. In actuality, the currents produced by the local winds would have northerly components and a tendency, therefore, to reduce the steady flow. On the days preceding the periods of observation the winds blew from the west and northwest. In view of the nearby land configurations, such winds could produce surface currents in a southerly or southeasterly direction. According to Ekman (4), the time taken during the transient state for a wind-driven current to reach approximately its equilibrium value is of the order of two to three hours. A similar argument indicates that local currents, produced by local winds on the days preceding the observations, would not endure for more than a few hours after the winds died away. It is therefore concluded that, although the local winds modify the steady flow, they do not by themselves account for it.

The only run-off into Hecate Strait which might account for the observed steady flow comes from the Skeena River. The surrounding land configuration and Coriolis force combine, however, to direct the river out-flow northward (5) rather than southward, and in such a way that it does not flow in the region of the current measurements.

CONCLUSIONS

At this position the tidal currents are rotary, with the dominant directions and velocity parallel to the coast-line. The surface currents rotate clockwise semi-diurnally with a maximum of 1 to 1½ knots southward, and the minimum less than 0.1 knot northward. The net progress of the water is southward at about 0.4 knot.

The bottom currents at 41 fathoms depth vary irregularly from 0.2 to about 0.6 knot, and rotate counterclockwise, opposite to the surface currents.

These observations define the character of the currents at the position and time of observation. There is no evidence that the component of steady southward flow is associated with wind or land drainage wherefore it is probably associated with the tidal circulation in some manner, and may be a transitory feature.

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Growth Hormone from Salmon Pituitary Glands[1,2]

By A. Jampolsky and W. S. Hoar[3]
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ABSTRACT

Injections of an alkaline extract of the anterior lobe of beef pituitary produced a prolonged acceleration of growth in rats and a temporary increase in weight of goldfish. A comparable extract of salmon pituitaries (*Oncorhynchus tshawytscha*) had no effect on growth of rats but produced a slight temporary increase in growth of goldfish. Negative effects of salmon extracts on rats are considered significant, but all effects on goldfish are questioned since the extracts were not free of toxicity.

INTRODUCTION

It is recognized that the pituitary gland of fishes produces a group of hormones comparable in nature to the pituitary hormones of higher vertebrates. However, a number of questions of a comparative nature are still unanswered. Some hormones which are recognized products of the mammalian gland have not yet been demonstrated in fishes, while others have been shown to vary in nature from one class of vertebrates to another and in some cases to be species specific in their action. The literature has recently been reviewed by Hoar (1951).

Pickford and Thompson (1948) established a definite growth acceleration in *Fundulus* injected with purified beef pituitary growth hormone. Although the extracts used were not free from thyrotrophic action, it seems likely that the increased weight was due to growth stimulation by the pituitary growth hormone. Comparable experiments in which extracts of fish pituitary are studied in relation to growth of mammals and/or fish have not yet been described. Such a study seems necessary to complete the comparative picture. In the experiments recorded here beef and salmon (*Oncorhynchus tshawytscha*) pituitaries were extracted in the same way and a comparison made of the effects of these extracts on rats and goldfish (*Carassius auratus*).

MATERIALS AND METHODS

Approximately 150 fresh beef pituitary glands were supplied by Canada Packers Ltd., Vancouver, B.C. British Columbia Packers Ltd. co-operated in the collection of about 5,000 fresh spring salmon (*O. tshawytscha*) pituitaries from fish brought to the Imperial Cannery, Steveston, B.C., during the early summer of 1949. The anterior lobes of the beef pituitary or the entire pituitary glands of

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[2]The data are taken from a thesis presented by A. Jampolsky in partial fulfilment of the requirements for the degree of Master of Arts at the University of British Columbia. They have been prepared for publication by W. S. Hoar.

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the salmon were used to prepare alkaline extracts as described by Evans and Simpson (1931). In macerating the soft fish pituitary glands it was not necessary to add the sand recommended for the mammalian tissue. Otherwise extraction procedures were the same. Extracts were passed through a Seitz filter and preserved with 1:10,000 merthiolate.

Two groups of female rats were injected. Group 1 consisted of 13 Wistar animals ranging from 200 to 244 grams in weight at the beginning of the test. The 22 female Wistar rats in the second group were five to six months old and weighed 119 to 182 grams when the injections were started.

The goldfish used varied in weight from 7 gm. to 14 gm. They were maintained at 25° C. in 28-litre aquaria and fed on a prepared aquarium fish food.

Both rats and goldfish were injected intraperitoneally each day and weighed at intervals of about one week.

RESULTS

Effect of Extracts on Rats

The first series of injections were designed to determine whether the extraction method did remove a growth-stimulating factor from the pituitary, and if so, to test its potency in accelerating the growth of rats.

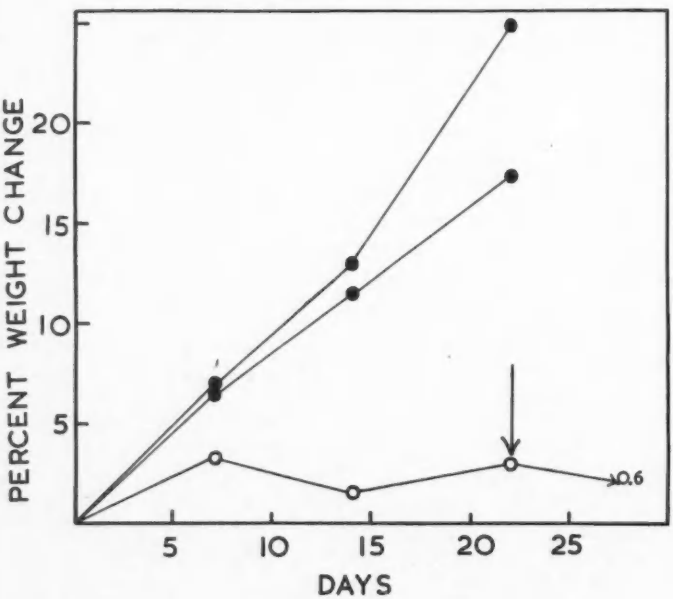

Figure 1. Response of rats (group 1) to pituitary extracts. Open circles, controls; Solid circles, beef pituitary extracts injected; upper line, 2-ml. dose; middle line, 1-ml. dose; vertical arrow, injection of controls for 21 days with 2 ml. fish pituitary extract.

Five uninjected, but handled, control rats were compared with two groups of four injected rats receiving either 1 ml. or 2 ml. of the beef pituitary extract per animal. Animals were injected daily and weighed weekly during the 22-day period. The results (Figure 1) show that a potent growth-accelerating factor was obtained from the beef glands by this method.

The five control rats used in these preliminary experiments were now injected daily with 2 ml. salmon pituitary extract for 21 days. Three showed a loss in weight (2.1, 5.9 and 6.5 per cent) while two showed a gain (0.9 and 2.4 per cent).

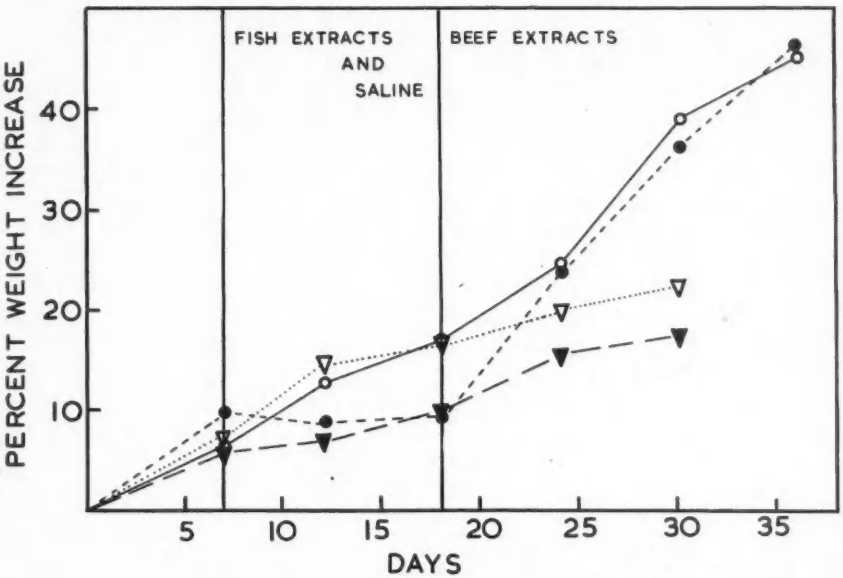

FIGURE 2. Response of rats (group 2) to pituitary extracts. Rats handled only during 7-day pre-injection period.

——— fish extract followed by beef extract;
– – – – saline followed by beef extract;
. . . . saline for entire injection period;
——— fish pituitary extract for entire period.

These experiments did not provide any evidence for growth-accelerating material in salmon pituitary similar to beef pituitary hormone in character and potency (Figure 1).

In the second group of experiments the test rats were below the "plateaued" weight (200-250 gm.) which shows the most marked response to injections of growth hormone. Five control rats were injected daily with 3 ml. saline for 23 days. Ten rats were injected daily with 3 ml. salmon pituitary extract for the same period. Two rats were injected daily for 11 days with 3 ml. fish pituitary extract followed by 18 daily injections of 2 ml. beef extract. Two rats were

treated similarly with saline followed by beef pituitary extract. The results, summarized in Figure 2, corroborate those of the preliminary test.

It is thus evident that the techniques used produced an active extract of beef pituitary but that extracts prepared in the same way from salmon glands had no effect on rats.

Effects of Extracts on Goldfish

In control experiments it was demonstrated that handling and injection of goldfish produce measurable changes in weight. Nine goldfish removed daily from the aquarium and handled for a brief period equivalent to that required for injection showed a 5 per cent increase in weight at the end of the first week, but thereafter the weight declined and was 5 per cent below the initial value at the end of the second and third week. Eleven goldfish injected daily with saline showed an average 5 per cent loss in weight at the end of five days. Two others similarly treated increased in weight by about the same amount during the first week and thereafter declined during the next two weeks to remain at about 5 per cent below the initial weight. It was concluded that handling and injecting techniques created $\pm$ 5 per cent weight change.

Both beef and salmon pituitary extracts proved so toxic that most of the goldfish died before satisfactory results could be obtained. Since saline-injected controls lived in good health, it is concluded that death was due to toxicity of the extracts. Nixo-Nicoscio (1940) found it necessary to remove the albumen from beef pituitary extracts before injecting them into carp. Extracts containing albumen killed the fish.

In spite of the toxicity of the extracts, suggestive data were obtained. Figure 3 is based on 39 goldfish injected daily with 1 ml. salmon extract and 19 injected with 1 ml. beef extract. It is evident that both beef and salmon pituitary extracts produce an increase in weight during the first five to seven days followed by a decline which may be due to the toxicity of the extracts. The 12 fish weighed after five days' treatment with beef extract showed a mean weight increase of 21 per cent, while the 12 fish receiving salmon extract for the same period showed a mean weight increase of 10.8 per cent.

Mortality was high during the second week and no fish survived longer than 19 days. Nine fish which received beef extract and survived longer than one week showed a mean weight gain of 18 per cent at the end of the first week, while 18 fish which received salmon extract and survived longer than one week gained 8.1 per cent.

Lengths of goldfish were recorded and scales examined. The maximum length difference recorded (2 mm.) was well within the range of error for duplicate measurements on single fish. No differences between scales of experimental and control fish were noted. Since the weight changes occurred so rapidly it is perhaps not surprising that the effect was not evident in scales or length measurement.

DISCUSSION

Growth of young rats was accelerated by extracts of beef pituitary, but showed no response to extracts prepared from salmon pituitaries. There are three possibilities for these negative findings.

In the first place salmon pituitary may not produce growth hormone. Present knowledge of pituitary physiology in other vertebrates makes this unlikely. However, it must remain a possibility until a potent growth-stimulating extract of fish pituitary can be prepared. In the present study this could not be established because of the toxicity of the extracts when injected into fish.

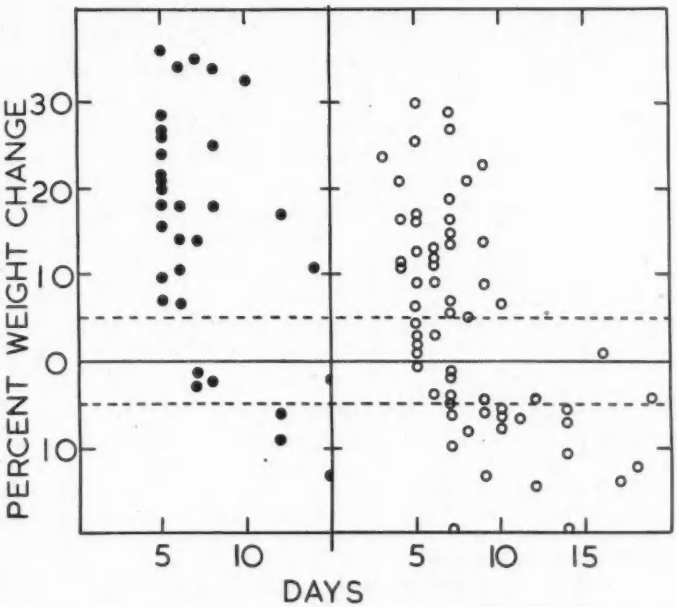

FIGURE 3. Response of goldfish to pituitary extracts. Horizontal broken lines show the expected 5 per cent variation due to handling and injecting. Solid circles, beef pituitary extracts; open circles, salmon pituitary extracts.

In the second place, fish growth hormone may be much less concentrated than beef hormone and larger doses may be necessary to produce an effect. Since the amount of salmon extract injected into rats was three times that required to produce a marked effect with the beef extract, this does not seem particularly likely.

In the third place the growth-stimulating factor may be somewhat specific in its action and fish hormone may be ineffective in mammals. Specificity of the gonadotropic hormones of the pituitary is recognized (Hoar, 1951), and this seems to be the most likely explanation.

The initial weight increase of about 21 per cent shown by goldfish injected with beef pituitary extracts is greater and appeared earlier than that reported for *Fundulus* by Pickford and Thompson (1948). However in *Fundulus* there was an initial weight loss during the first week which may have been due in part to handling, whereas control goldfish usually showed an increase in weight. Thus, in view of the difference in the reaction of controls, the actual response to hormone may have been similar.

Since the extracts used in the present investigation were toxic, the increase recorded here may be due entirely to osmotic disturbance. Whether the increase in weight of goldfish is due to growth hormone or to osmotic disturbance, it is evident that salmon extracts affect goldfish in essentially the same way as beef extracts.

It is possible that the goldfish mortality, which became progressively more marked with time, was due to an antibody-antigen reaction produced in goldfish by the foreign beef protein. If such were the case, the initial weight increase might reflect a response to growth hormone. These experiments are inconclusive. The failure of rats to respond to fish pituitary extracts is considered significant, but the effects obtained on goldfish cannot with certainty be attributed to growth hormone.

ACKNOWLEDGMENT

We are indebted to Dr. Grace Pickford of Yale University for her encouragement and advice during the preparation of this manuscript.

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The Presence of Androgens in Chum Salmon (*Oncorhynchus keta* Walbaum)[1,2]

By Gilbert D. Potter and William S. Hoar[3]
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ABSTRACT

Testes of mature chum salmon (*Oncorhynchus keta* Walbaum) were examined histologically for interstitial cells and extracts of testes assayed biologically for the presence of androgens. The histological examination showed numerous interstitial cells similar to those described in some other fish and in mammals. The bioassay established the presence of androgenic substance (probably testosterone). The amount present in salmon testes was calculated to be roughly equivalent to the amount present in mammalian testes.

INTRODUCTION

There is ample evidence that reproductive behaviour and sexual characters are under endocrine control in fish as in other vertebrates (Hoar, 1951). However, the hormones have not been identified and studied physiologically, nor has the source of the material within the gonad been established. The presence of interstitial glandular tissue in the testes of fish has not been universally recognized (Hoar, 1951).

Hazleton and Goodrich (1937) obtained a substance by alcohol benzene extraction of 3.1 kg. of salmon testes (*Oncorhynchus kisutch*?) which, when injected into two capons, produced a definite acceleration in comb growth. They concluded that testes of silver salmon contain a substance similar physiologically to sex hormone. This brief communication seems to describe the only attempt to extract and study the hormones in fish gonads.

In the present investigation testes of chum salmon (*Oncorhynchus keta*) were examined histologically for interstitial cells and extracts from chum salmon testes assayed biologically for androgens.

MATERIALS AND METHODS

Maturing testes were collected from the commercial catches of chum salmon. We are indebted to Mr. Norman Cook of the Pacific Fisheries Experimental Station, Fisheries Research Board of Canada, for this material. The testes used for histological work were obtained at Cultus Lake, B.C., from spawning fish.

Gallagher and Koch's (1929) method was used to extract a lipid fraction from the testes. Their procedure was modified by first freezing and then lyophilizing minced salmon testes to give a dry powder. This had the advantage

[1]Received for publication May 6, 1953.

[2]The data are taken from a thesis presented by G. D. Potter in partial fulfilment of the requirements for the degree of Master of Arts at the University of British Columbia. W. S. Hoar prepared the manuscript for publication.

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of eliminating a preliminary extraction of the tissue with large amounts of 95 per cent alcohol and re-extracting the lipid fraction with benzene. Two lots of tissue were studied. The first extract was prepared from 12 lbs. (5.5 kg.) of testes. The powdered, lyophilized tissue was extracted for 16 hours with hot acetone in a large soxhlet-type extractor which held approximately 100 g. of the powdered tissue. This procedure separated the bulk of the tissue proteins and phospholipids from the fats and sterols in the acetone soluble fraction. The acetone extracts were combined, chilled at —10° C. and filtered. The remainder of the procedure was carried out according to the method of Gallagher and Koch (1929). The second extract was prepared in the same way from 24 lbs. (11 kg.) of tissue. The by-products of the fractionation were reserved for later testing. For the purpose of convenience the extracts obtained are numbered as follows:

1. Alcohol-ether soluble fraction from first extraction (12 lbs. of tissue)
2. Alcohol-ether soluble fraction from second extraction (24 lbs. of tissue)
3. White crystalline precipitate from hexane soluble fraction of the second extraction.
4. remainder of hexane soluble fraction (combined from both extractions).

Extracts 1 and 2 were each dissolved in 10 ml. of neutral corn oil (Mazola). Extract 3 was dissolved in 20 ml. of corn oil and extract 4 was not diluted. The preparations were stored in ampoules in the refrigerator until used for essay.

The extracts were assayed biologically (Frank *et al.*, 1942; Koch, 1937) by measuring the comb growth of male chicks ranging in age from two days to one week as indicated in the legend of Table I. Chicks were fed on standard ration and maintained at constant temperature. Professor J. Biely of the Poultry Nutrition Laboratory, University of British Columbia, supplied all chicks as well as facilities for the care of those used in tests 2 to 4. It is a pleasure to acknowledge this assistance.

TABLE I. Summary of results of bioassay. Cockerels used for extract 1 were New Hampshires, 7 days old at the start of the experiment; all others were from a single brood of white Leghorns, 2 days old at commencement of experiment. Chicks were sacrificed 2 days after last injection.

Extract No.	No. of chicks	Daily dose	Days injected	Average comb growth response	
				"length + height"	comb wt. (*mg.*) / body wt. (g.)
		ml.		*mm.*	
1	7	0.20	10	13.8	—
Control for 1	8	—	—	8.7	—
2	5	0.25	7	24.0	1.76
3	10	0.25	7	16.0	0.579
4	15	0.50	7	12.0	0.172
Control for 2, 3 and 4	15	—	7	15.0	0.564

For the purpose of histological examination mature salmon testes were fixed in Bouin's picric-acetic acid-formol mixture, imbedded in paraffin, cut at 5μ, and stained with Harris' hematoxylin and eosin.

RESULTS

Histological

The histological preparations of the salmon testes showed that an abundance of interstitial material was present (Figures 1, 2 and 3). Although no special staining techniques were used, it appears that there are numerous cells in the salmon testis similar to those described by Courrier (1921) and Craig-Bennett (1931). These are large cells with a granular cytoplasm, containing a large nucleus with a considerable amount of chromatin and a prominent nucleolus. They are also similar to the Leydig cells as described for mammalian testes (Hooker, 1948). The septa of the crypts contract after the release of the spermatozoa, allowing the connective tissue elements of the septa to widen. The interstitial tissue is especially prominent in spent salmon testes. This is also the case with *Gasterosteus* just after mating (Craig-Bennett, 1931). Thus, it appears that salmon possess interstitial cells of Leydig although they are claimed to be absent in some species of fish (van Oordt, 1925). It should be noted that Craig-Bennett (1931) finds the presence of interstitial tissue is largely dependent on the season of the year. During the breeding season it is most abundant but in the quiescent period it may be inconspicuous.

Bioassay of Extracts

The tests are described in Table I. Chicks injected with extract 1 were not maintained under satisfactory conditions. Three died from the control group and two from the experimental group. The injections did, however, produce a pronounced acceleration in comb growth. The mean "length + height" measurement for the controls was 8.7 mm. (range 6.5–11.0 mm.) as against 13.8 mm. (range 11–21 mm.) for the experimentals.

The remainder of the tests were done under conditions ideally controlled for healthy chicks. The results are presented in Figures 4, 5 and 6. It is evident that only extract 2 of this second fractionation produced any acceleration in growth of secondary sex characters.

Evidently the hexane fraction was toxic (extract 4) as 15 of the chicks died in this group and those that lived were retarded in growth of body as well as comb and wattles. The chicks injected with extract 2 showed a comb growth of about three times that of the controls using the relation (Dorfman, 1948):

$$\frac{\text{comb weight in mg.}}{\text{body weight in gm.}}$$

The average "length + height" comb index for the controls was 15 mm. (range 12–17 mm.); for the experimentals (extract 2) this index was 24 mm. (range 20–29 mm.). The growth effect is illustrated in Figures 5 and 6.

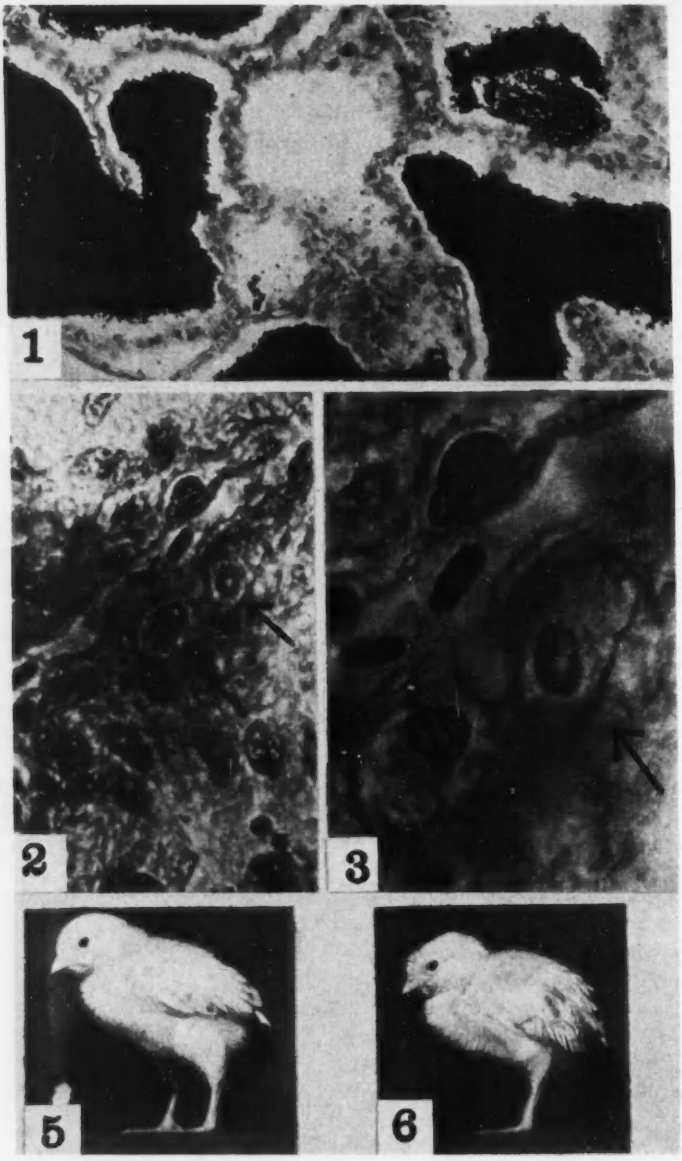

FIGURE 1. Photomicrograph (X140) of mature salmon testis. Note light areas of interstitial tissue between black masses of spermatozoa.

FIGURE 2. Photomicrograph (X950) of mature salmon testis. Arrows point to interstitial cells.

FIGURE 3. Photomicrograph (X1840) of mature salmon testis. Arrows point to interstitial cells.

FIGURE 5. White Leghorn cockerel, 10 days old, injected with 0.3 ml. neutral corn oil daily for 7 days.

FIGURE 6. White Leghorn cockerel, 10 days old, injected with 0.3 ml. of extract 2 in neutral corn oil daily for 7 days. Compare comb and wattle with control, Figure 5.

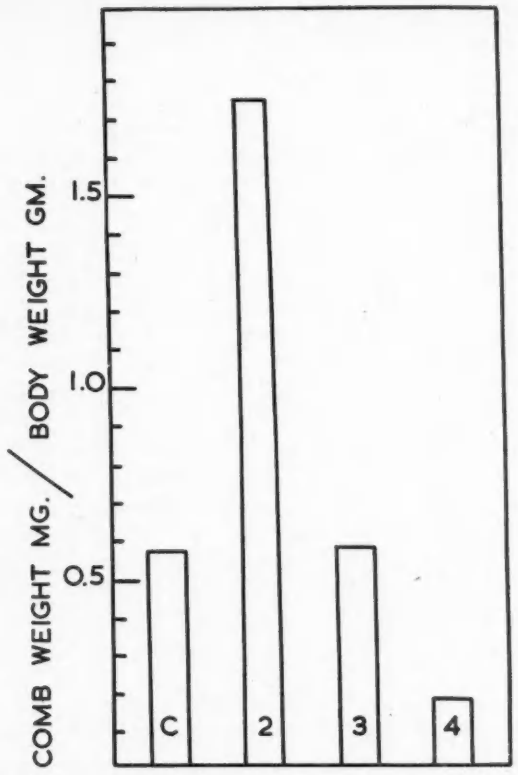

FIGURE 4. Histogram showing effect of extracts from salmon testes on the comb growth of cockerels. C, Control; extracts 2, 3, 4 are described in text.

DISCUSSION

The histological preparations provide evidence for the presence of specialized interstitial tissue in the testis of the chum salmon at spawning time and it may be assumed to be the source of the androgen(s) produced.

The chick comb-growth tests show that an active androgen was extracted in the lipid soluble fraction. Extracts 1 and 2 showed definite evidence of active sex hormone. Quantitative assay was not feasible since the amounts were so small. Only a general approximation of the amount of androgen in salmon testes is possible.

One international unit of male hormone has been established as 100γ of crystalline androsterone (Koch, 1937). This is equivalent to the capon unit—"that amount of hormone when injected daily for five days, yields an average of 5 mm. increase in length plus height of combs of at least 5 brown leghorn capons" (Gallagher and Koch, 1935).

Chicks injected with salmon extract 2 showed a length plus height increase of 9 mm. The chick is a less sensitive assay animal than the capon, and thus this is equivalent to at least 2 capon units per chick per day. Since, however, these chicks were injected for seven days, the total hormone used is equivalent to 36 capon units (5/7 of 5 days x 5 chicks x 2 CU). This amount was obtained from 24 lbs. of salmon testes and the potency is, thus, equivalent to 300 mg. of crystalline androsterone per ton of tissue, or 50 mg. of testosterone per ton of tissue.

Another approximation is based on the work of Dorfman (1948). The results obtained in the above experiment appear to be equivalent to a dosage of about 160 gamma of testosterone propionate per chick by innunction. Thus 160 gamma administered to five chicks gives about 800 gamma in 24 lbs. of tissue or about 66 mg. per ton of tissue.

These estimations give an approximation of the amounts of androgenic material present in the salmon testes. Values of 50 to 70 mg. per ton compare favourably with values for mammalian tissues. Bull testes, the most potent known mammalian source, have from 90–270 mg. per ton of tissue and other mammalian species have somewhat less.

It appears that an extract similar to testosterone has been obtained. The active material was present in the same fraction as that in which testosterone is found (Gallagher and Koch, 1935). Furthermore, this extract was of the same order of androgenic activity per unit weight of testicular tissue as testosterone found in mammalian species.

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The Behaviour of Juvenile Pacific Salmon, with Particular Reference to the Sockeye (*Oncorhynchus nerka*)[1]

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ABSTRACT

Behaviour patterns of juvenile sockeye salmon in fresh water are compared with those of chum and coho salmon. Both sockeye and chum fry are schooling fish, responding positively to currents and avoiding shallow waters. Of the two species, chums, however, form more active schools, travel more rapidly, have a less marked cover reaction and prefer stronger light and shallower water. Sockeye smolts, in contrast to coho smolts, are more active, show little thigmotactic and territorial behaviour and a more persistent response to current. The experimental findings are discussed in relation to the migratory behaviour of these fish. It is suggested that sockeye fry, emerging from cover as the light intensity falls are displaced downstream after dark. Moderate activity and a marked preference for deep water are mechanisms postulated for continued residence of sockeye fry in lakes. Further it is suggested that the smolt exodus is due to heightened general activity, both day and night, associated with strong response to current. This brings sockeye smolts into the outflow from the lake where they hold position during the day but are displaced down the river after dark. Coho smolts, responding less vigorously to currents and maintaining a measure of contact with specific objects in their environment, move seaward more slowly than sockeye.

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INTRODUCTION

BEHAVIOUR PATTERNS of chum, pink and coho salmon have been analysed in relation to their seaward migration (Hoar, 1951). In the present study, a comparable analysis is attempted for juvenile sockeye. The comparative method used in the previous study has again been employed. In general, it requires the accurate recording, at regular intervals, of the activities and positions of a definite number of fish held in a readily observable area. The nature of the area varies with the object of the experiment and may or may not attempt to simulate some part of the fish's natural environment. Lorenz (1950) has recently emphasized the importance of comparative methods in the analysis of innate behaviour. Such an approach seems ideal for the genus *Oncorhynchus*. Different species of comparable size and development, studied under identical conditions, will exhibit similarities and differences which permit an evaluation of the basic mechanisms responsible for the established events in their life histories.

Particular emphasis is placed on the comparison of sockeye fry with chum fry and sockeye smolts with coho smolts. Sockeye and chum fry are of comparable age and size but have a different life history in that chum fry move into the sea while sockeye fry usually migrate into lakes. Sockeye smolts and coho smolts are likewise of comparable age and size and have both spent at least one year in fresh water, but differ in that the sockeye move seaward from a lake while the coho are leaving a river. A comparison of these fish may be expected to suggest factors controlling movements of salmonids into lakes and oceans.

Although the main objective has been a general description of the innate behaviour patterns of juvenile sockeye, new experimental data have been obtained for both chum and coho salmon. These data are presented to verify earlier observations and to give a clearer picture of some of the details of juvenile chum and coho salmon behaviour.

MATERIALS AND METHODS

Experiments were carried out at Port John, British Columbia, during the summers of 1951 and 1952. Chum salmon fry (*Oncorhynchus keta*), coho smolts (*O. kisutch*), and sockeye smolts (*O. nerka*) were procured from a trap operated at the head of tide on Hooknose Creek which drains Port John Lake. Sockeye fry were also obtained from this trap in 1952 but in 1951 were

taken from a trap operated at the mouth of a small creek draining into Port John Lake. Since the downstream movement of these fish is completed in early June a stock of 200-300 of each species and age class was maintained for experimental purposes. The two species of smolts were retained in separate pens (180 × 90 cm.) and the sockeye and chum fry together in a similar pen or a trough. Running water was provided from Hooknose Creek and the fish were maintained in evident good health for the period of the experiments on a mash of canned salmon and pablum (Meade Johnson Co.,) fed three to four times per day. Coho fry were captured as required for the experiments. The mean fork lengths, as determined from samples of fish preserved at the end of the 1951 experiments, are given in Table I.

TABLE I. Fork lengths for samples of experimental fish.

	Specimens measured	Mean length	Standard deviation
		mm.	*mm.*
Coho smolts	35	106.8	7.5
Coho fry	50	38.3	1.9
Chum fry	50	40.3	2.7
Sockeye smolts	50	101.5	9.0
Sockeye fry	50	28.1	1.5

Unless otherwise indicated, experiments were carried out in a shelter where the light intensity varied diurnally but was always much lower than out of doors. Maximum values of 150 foot-candles were sometimes recorded in the shack, while midday light intensities out of doors at Port John sometimes reached 10,000 foot-candles.

Four sheet-metal troughs were variously adapted for most of the comparisons. These troughs were 240 cm. long, 25 cm. wide, and 19 cm. deep. A removable screen 15 cm. from one end separated an area containing an overflow pipe (130 mm. high) from the main portion of the trough and thus limited the working length of the trough to 225 cm. The troughs were painted inside with aluminum engine enamel. Details of the arrangements within these metal troughs and other pieces of apparatus used in the investigation are described in connection with the various experiments.

Water, for all experiments, was drawn from a storage tank of about 7,000 litres capacity. The tank was filled in the morning and evening and temperature variations in the laboratory water were less than those occurring in Hooknose Creek.

Positions of fish in the different areas of observation were recorded at either one-half or one-minute intervals. Observations on the different groups of fish were made for 15-minute periods, five times per day. In general, experiments were set up about 11:00 a.m. each day and observations made at 2:00 p.m., 4:00, 7:00 p.m., and at 7:00 a.m. and 10:00 a.m. the next morning. To

prevent conditioning, new groups of fish were seined from the retaining pens each morning and those used on the previous day then returned to the pens. In some experiments the same groups of fish were observed for two days. Troughs were drained and cleaned when the groups of fish were changed. Additional procedures can be more conveniently given in connection with the experiments.

RESULTS

It is emphasized, at the outset, that all statements made concerning the behaviour of these young salmon are based on observations of their activities in troughs, tanks and aquaria. Any activities observed in streams as well as speculations concerning mechanisms of migration are clearly indicated as such. It may be added that the work of the past 20 years on innate behaviour (Lorenz, 1950) would suggest that the behaviour patterns observed under experimental conditions will also appear in nature. However, it remains for the ecologist to show how these ethological experiments are related to the activities of young salmon in their native surroundings.

All of the behaviour patterns observed in juvenile sockeye have already been described for other species of *Oncorhynchus* (Hoar, 1951). No different activities have been observed. In general, juvenile sockeye resemble pink and chum salmon in that they form close aggregates, schools or mills. Unlike the coho they show little relation to objects in the environment other than the various members of their school. In detail, however, there are marked differences in intensity of reactions and these differences seem readily related to the characteristic life history of the sockeye.

Aggregating Behaviour

SOCKEYE FRY

Although sockeye fry, emerging from the gravel, can best be described as schooling fish, their behaviour differs markedly from that of chum and pink fry (*Oncorhynchus gorbuscha*) at a comparable stage of development. Whereas chum and pink fry typically form an actively moving school with individuals "similarly oriented, uniformly spaced and moving at a uniform pace" (Breder and Halpern, 1946), the sockeye fry form more stationary aggregates. They do travel, as will be described later, but often remain almost motionless for long periods. Individuals are uniformly spaced but variously oriented and inactive. Many rest, head up, with the body at an angle of about 30° to the horizontal while the group remains stationary or slowly oscillates. When startled, sockeye fry swim away in a characteristic school. These differences can be quite simply demonstrated by placing large groups of fry in buckets. Chum or pink fry quickly initiate a circular school, swimming rapidly against the current thus developed. Sockeye fry remain relatively quiet, variously oriented, near the bottom. This arrangement of the sockeye fry was particularly evident in the deep water column described below.

Distribution of sockeye fry was studied quantitatively in the 180-cm.-long aquarium previously described (Hoar, 1951). Chi-square values, for departure of 12 fish from an average distribution of two fish per 30 cm., are plotted in Figure 1. These values are strictly comparable to those earlier recorded for chum, pink and coho (Hoar, 1951, Figure 1). Duplicate experiments with nine 20-minute periods of observation gave total chi-square values of 12,287 and 13,670 with 1,800 degrees of freedom. These are, on the whole, slightly higher

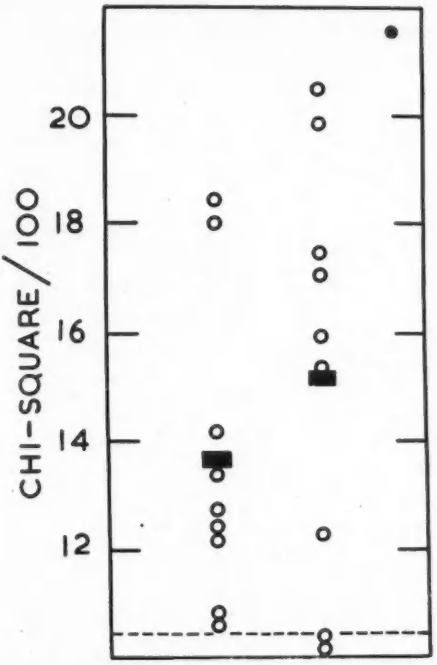

FIGURE 1. Distribution of sockeye fry. Circles, total chi-square values for 20-minute periods (40 positions); solid rectangles, means for values represented by each vertical series of circles. Each vertical series represents a separate group of fish. Values greater than 253.12 (dotted line) indicate departure from the average distribution of 2 fish per compartment at the 99 per cent level of confidence (200 degrees of freedom).

than the values for pink and chum salmon. Comparisons of chum and sockeye fry in the larger metal troughs likewise show a more compact but less active grouping on the part of the sockeye (Figure 2). This may be associated with their small size (Table I) rather than with fundamental differences in behaviour.

SOCKEYE AND COHO SMOLT

Aggregating behaviour of sockeye and coho smolts was compared in one of the 225-cm. metal troughs divided transversely in half by a perforated plywood partition. Black lines were painted on the trough bottom for ease in recording

positions of fish. Each half section of the trough was marked as follows: three equally spaced transverse lines divided the area into four parts, identical except for the end walls. A line painted around the margin of the area, at a distance of 6 cm. from the periphery marked off a "peripheral area" (1,506 sq. cm.) from a "central area" (1,360 sq. cm.). In any experiment 12 sockeye smolt were placed in one end and 12 coho smolt in the other. The locations of the groups were alternated from experiment to experiment. Positions were plotted each minute for five 15-minute periods in an experiment. Numbers of fish were recorded in each of the four major areas as well as numbers in the central and in the peripheral regions. Half of the fish on the marginal lines were considered inside and half outside.

Data for numbers in the four major areas (eight experiments), summarized in Table II, indicate that coho smolts show a greater tendency to group (higher

TABLE II. Comparison of the distribution of sockeye and coho smolt. Positions were recorded at one-minute intervals for 15 minutes; all values tabulated are daily totals for 5 of these 15-minute periods (75 minutes observation); chi-square totals for smolts moving in 4 areas thus have 225 degrees of freedom; means and standard deviations are based on the 40 individual observation periods.

Starting date, May, 1951	Temperature range °C.	Chi-square totals		Total number of fish: Central area		Total number of fish: Peripheral area	
		Sockeye	Coho	Sockeye	Coho	Sockeye	Coho
22	9.5–10.5	348	1,053	581	116	319	784
24	8.5–9.0	773	989	727	180	173	720
25	8.0–9.1	693	1,203	440	464	460	436
26	8.0–10.9	835	1,034	624	173	276	727
27	9.0–11.2	933	1,715	691	112	209	788
28	9.9–10.0	810	1,241	633	133	267	767
30	9.0–13.5	1,589	1,433	531	178	369	722
31	10.2–13.0	1,318	2,006	578	141	322	759
Means				120.1	37.4	59.9	142.6
Standard deviations				23.0	26.9	23.0	26.9

chi-square totals). This is perhaps unexpected since sockeye are schooling fish while coho form less orderly aggregations (Hoar, 1951). Two factors appear to explain the observed difference in distribution. Sockeye occupy the centre of the trough in a loose school, are regularly on the move and, with 12 fish in the area, usually spread over at least two compartments. Coho, on the other hand, remain in the peripheral areas. In seven out of eight experiments coho nipped and an individual defended some area of the trough, driving other individuals to one end. In one experiment (May 24) coho did not show nipping or territorial behaviour but the distribution was of the same nature (Table II). A less detailed comparison of groups of 20 smolt in an undivided trough also gave chi-square values which were consistently higher for coho than sockeye.

The series of eight experiments just discussed was also designed to study contact reactions or thigmotaxis. The impression obtained in working with these

fish is that coho smolt often move along the periphery of the trough and regularly rest at the ends or near the sides. Sockeye smolt, on the other hand, are centrally located and rarely rest in the peripheral regions. If true thigmotactic reactions exist they may be important in directing fish along shores and may explain differences in the distribution and behaviour of the species. Analysis of the data (Table II) shows that, over an extended period, sockeye smolt occupy the central areas of the trough while the coho smolts are peripherally located. However, it does not necessarily follow that coho exhibit a thigmotactic response which is absent or negative in sockeye. The peripheral location of the coho may depend entirely on their territorial behaviour. On the other hand, it is emphasized that the reaction was strongly marked in an experiment (May 24) where no territorial behaviour was evident, that it appears as soon as the fish are introduced into an area while territoriality is often not evident during the first periods of observation; and that it may presumably be related to the activities of a fish which spends its early life in shallows near solid objects rather than in a pelagic manner like sockeye. It may also be mentioned that nipping was observed in the sockeye groups but the nipped individuals move into the school rather than to the periphery. It is, therefore, suggested that the coho smolts do show a positive reaction to solid objects in their environment and that this reaction is negative or absent in sockeye smolts. Breder (1951) notes that schools of *Jenkinsia* maintain a specific distance from solid vertical objects.

Nipping and Defence of Territory

Nipping and defence of territory, which is so characteristic of young coho (Hoar, 1951), is rarely observed in juvenile sockeye. Nipping or chasing behaviour by sockeye fry was recorded only five times in two summers. Sockeye smolts, on the other hand, nipped more frequently and sometimes showed defence of territory. Nipping by the sockeye smolts, however, does not have the vicious appearance of the coho nipping and never releases a retaliation (threatening and fighting) which is so characteristic of juvenile *Salmo gairdneri* (unpublished data). Nipping behaviour in coho characteristically shows three components, a swift chasing or darting movement, the nipping or biting act and, finally, a sharp turn of the body to carry the individual back toward the point from which it started. Sockeye smolts may show the same three movements, but more frequently they swim swiftly forward to nip with considerably less vigour and continue swimming in the same direction. Thus, chasing is the most obvious part of the aggressive behaviour of sockeye smolts.

Nippings by sockeye and coho smolt are compared quantitatively in Table III. This table is based on a study of four groups of each kind of smolt. Groups of 12 sockeye and 12 coho smolts were studied alternately in the 180-cm.-long aquarium. In each experiment the fish were watched for six of the standard 15-minute observation periods. Total number of nips was recorded. In addition, the number of 180° turns made by fish was noted. This turning activity is a characteristic feature of sockeye smolts confined to the aquarium. It is a part of

the schooling and milling behaviour. When the fish cannot move any distance they remain in a loose group but are still active. As an individual swims beyond visual contact with the other fish it turns sharply into the group. This 180° turn involves two apparently "effortless" contractions of the body, requires about one-third second and may be directed either to the left or to the right. Turns made by the coho smolts are less regular and stereotyped and are a part of an entirely different behaviour pattern, namely, their nipping, chasing and territorial behaviour.

The data summarized in Table III show two distinct differences in the behaviour of sockeye and coho smolts. In the first place the sockeye smolts are

TABLE III. Comparison of nipping and territorial behaviour of coho and sockeye smolts. Values recorded are total counts for 90 minutes of observation spread over 6 of the standard periods. Means are based on totals for the 24 separate observation periods. The experiment ran from June 1 to 12, 1951 and the coho and sockeye groups were alternated from day to day.

Coho Smolts[a]				Sockeye Smolts			
Temp. range °C.	Turns	Nips	Territories	Temp. range °C.	Turns	Nips	Territories
10.5–14.5	133	43	6	11.0–14.0	1,112	46	3
12.0–16.0	723	208	9	14.9–17.0	1,214	33	0
12.5–14.5	515	175	7	14.0–15.5	1,154	6	0
12.5–13.0	648	270	13	12.0–13.0	1,328	4	0
Sum	2,019	696	37		4,808	89	3
Mean	84	29	1.5		200	3.7	0.125
Standard deviation	11.6	5.4	0.19		6.6		

[a]Mean values of 93.5 nips and 2.3 territories for a group of 12 coho parr (60–85 mm. long; 6 observation periods) confirm an earlier conclusion (Hoar, 1951) that territorial behaviour is reduced in coho at the time of smolt transformation.

more active, making more than twice as many turns per unit time as the coho. This is discussed in a later section. In the second place, nipping appeared much less frequently in sockeye and was more rarely associated with defence of territory. In fact, territorial defence by the sockeye was so infrequently recorded in this experiment that its existence as a part of the animal's normal activities seemed questionable. Additional experiments were therefore planned. Seven groups of 12 sockeye smolts were watched in the 225-cm. troughs for 10-minute intervals and a total of 68 observation periods. In alternate periods of observation a cover was placed over one of the four equal areas of a trough. The cover was located by random numbers and placed in position at least two hours prior to observation. In this experiment 12 territories were established in the 68 periods. The mean value of 0.177 territories per period does not differ greatly from the earlier figure of 0.125 (Table III). Ten of the 12 territories were established in relation to cover.

A different type of territorial activity was sometimes observed when groups of sockeye smolts were confined in the 225-cm. troughs. This has the appearance of a definite exploration or investigation on the part of the fish and may be characteristic of schooling salmon, since it has also been observed with chum and pink underyearlings from salt water. The group as a whole is established in one or other end area of a trough. An individual moves out from the group and slowly swims almost to the other end of the trough. The others follow closely in a group. Suddenly an individual in advance turns sharply and quickly swims back. The rest of the group turn and school closely with the leading individual. The return journey requires only a fraction of the time of the initial exploratory movement. This behaviour may continue for long periods.

Roaming in Quiet Water

Under certain conditions schooling salmon exhibit a regular pattern of movement in an enclosed area of quiet water. Sockeye and chum fry in the 225-cm.-long metal troughs often swim back and forth in a predictable manner for long periods. This activity was used to compare the swimming speeds of the two species of fry. Observations were made on groups of 25 fish. A pair of troughs placed side by side in the laboratory provided identical light and temperature conditions for comparisons of the groups. Four equally-spaced lines were painted on the bottom of the trough for ease of recording. Five different groups were studied at the usual observation periods for two days (total of 1,200 positions recorded for each species).

Rates of migration for sockeye and chum fry are compared in Table IV. A typical recording is shown in Figure 2. The precise rates of travel tabulated may have little relation to the rates of swimming in nature. It is evident, however, that the chums are moving about twice as rapidly as sockeye under the same conditions of temperature and light. This may be due to size differences but the fact remains that chum will cover more territory at this stage of their life cycle.

It is of interest to know whether this active wandering in quiet water forms a regular part of the behaviour of schooling salmon fry. The aluminum surface of the trough is very different from the bottom of a stream and fish may be excessively stimulated by light from below. Consequently these findings were checked with experiments in which the bottoms of the troughs were covered to a depth of about 3 cm. with sand and gravel. From 10 to 15 angular stones scattered over the surface of the gravel provided possible cover. In duplicate experiments, chum and sockeye fry were compared for 20 observation periods of 15 minutes duration. On 70 per cent of the occasions chum fry showed a regular migration while sockeye showed this activity only 50 per cent of the times. These values are to be compared with 95 per cent for chums and 77.5 per cent for sockeye on the aluminum-painted surfaces. Lower temperatures (8° to 11°C.) in the troughs containing sand and gravel may have been responsible for the smaller number of migrations. The point emphasized here, however, is that this roaming behaviour may be expected of both groups in quiet water even though

TABLE IV. Mean number of excursions per 15 minutes by schools of sockeye and chum fry, and cover responses measured as total minutes under cover during 150 minutes observation.

Commencement date June	Temperature range °C.	Number of 225-cm. excursions		Cover response	
		Sockeye	Chums	Sockeye	Chums
1/51	10.5–13.7	8.5	9.5	—	—
2/51	13.0–15.0	8.6	16.3	99	41
4/51	13.5–17.0	9.1	22.0	94	5
6/51	12.5–15.5	10.2	21.6	120	14
1/52	10.0–10.5	5.2	18.2	—	—
Mean for all observation periods		8.7	18.4	10.4[a]	2.0[a]
Standard deviation		4.4	6.7	6.1	3.2

[a] Based on the 30 separate 15-minute periods.

normal cover in the form of rocks and gravel is present. The relation to light intensity is treated below.

Sockeye smolts less frequently show regular wandering in the long troughs. Six groups of 12 fish each were watched for 10 of the regular observation periods. Characteristic roaming occurred in only 16.7 per cent of the periods (10 out

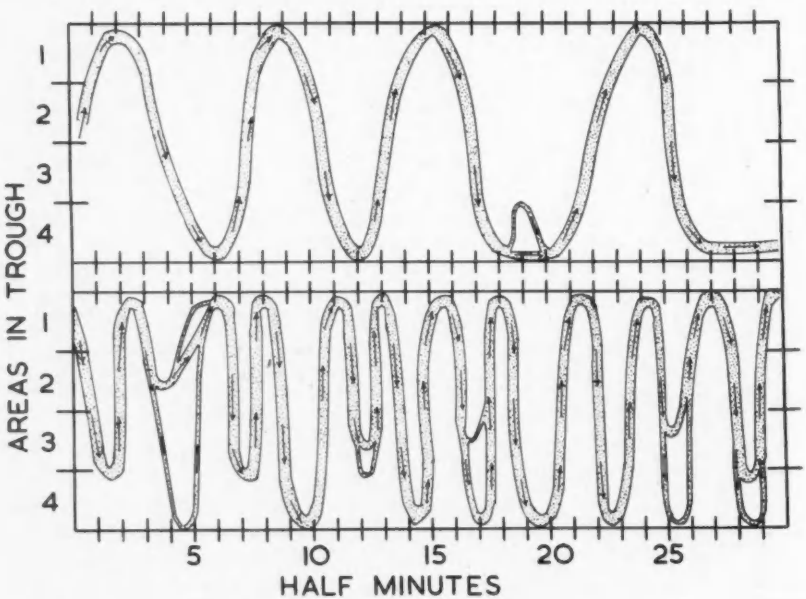

FIGURE 2. Characteristic roaming of groups of 25 sockeye fry (above) and 25 chum fry (below) in the 225-cm. troughs. Width of line indicates relative number of fish involved in journey; recording at 8:00 p.m., June 7, 1951, 14.0° C.

of 60). The mean number of excursions for the periods of activity was 17.6 (temperature range 8.5° to 12.5°C.). Sockeye smolts swim more rapidly than sockeye fry and at about the same rate as chum fry.

Cover Reactions

SOCKEYE AND CHUM FRY

Cover reactions of sockeye and chum fry were compared in the same areas and for the same groups of fish described in the previous experiments (Table IV, 1951 series). Following a record of swimming rates, a piece of aluminum-coated plywood of the same size as one of the areas was floated above an area. Fish were thus startled and took shelter under the cover. Their positions were then recorded at one-minute intervals for an additional period of 15 minutes. The plywood cover was located by random numbers. The data for three experiments (450 positions for each species) are presented in Table IV. An additional experiment in 1952, involving four observation periods at a lower temperature (10.0°–10.5°C.) gave similar results with mean occupancy of 3.5 minutes for chums and 13.0 minutes for sockeye.

The cover reaction of sockeye fry is evidently much stronger than that of chum fry. This experiment is interesting to watch. When cover is provided, both groups are disturbed and normally dart under it, but the sockeye remain there while chums soon assume their regular to-and-fro movement passing back and forth with no apparent regard for the cover. It should be added that sockeye fry do frequently emerge but after a longer period of time (10 to 20 min.) and particularly at low light intensities. They may likewise migrate to and fro without apparent regard for cover.

Responses of chum and sockeye fry to cover were also compared in duplicate experiments where the cover was suspended midway between the bottom of the tank and the surface of the water. The reaction was the same. In to-and-fro swimming both chum and sockeye fry passed over or under the cover about an equal number of times.

The above experiments might suggest that a cover reaction is absent in chum fry. This impression is quickly altered if an attempt is made to capture fry from the troughs which contain gravel and stones. It is evident that sockeye find shelter more quickly and, perhaps because of smaller size, are more difficult to locate, but chums readily take shelter under stones and can only be captured by removing the larger stones and most of the water.

SOCKEYE AND COHO SMOLT

Sockeye smolt likewise show a strong positive response to cover. In observations made with three groups of smolt in troughs situated under direct sunlight all fish remained continuously under cover in 12 of 16 observation periods. Not more than 40 per cent of the fish emerged at any time during the observations. At least one of the major variations from total positive response was related to a sudden elevation in temperature. Huntsman (1942) points out that high temperature makes Atlantic salmon insensitive to light.

Under less intense lighting of the laboratory, sockeye smolt regularly emerge from the cover area. Six different groups of 12 fish were observed for 10-minute periods five times per day for two successive days. Alternately an area was covered or the cover removed following a recording. Positions of fish were noted at one-minute intervals with respect to four equal areas of the 225-cm. troughs, and differences in distribution compared by a chi-square analysis (Table V). Higher values found when cover is present are due to groups of fish lingering under the cover. The order is consistent in all experiments.

Coho smolt were studied in experiments similar to those just described for sockeye. However, defence of territory complicates this study and figures suggesting that the cover reaction is less intense in coho are probably misleading. The cover area is frequently, although not always, the area defended.

TABLE V. Chi-square values for 12 sockeye smolts moving in 4 areas of a 225-cm. trough. Positions were recorded at six 2-minute intervals. Tabulated values are totals for 5 observation periods (30 positions) with one group of fish (90 degrees of freedom); A and B were paired troughs placed side by side.

Experiment		Temperature range °C.	Chi-square	
			Cover	No cover
June 10	A	10.8–12.8	541	385
	B		869	546
June 12	A	9.0–11.5	472	454
	B		680	341
June 14	A	8.3–12.0	612	429
	B		561	501
Total			3,735	2,656

DEPTH PREFERENCE

These responses to cover are probably evidence of a preference on the part of the fish for light of a definite intensity. In the schooling pelagic sockeye, at any rate, this reaction would seem to be related to preferred light or depth rather than a tendency to go under solid objects. The study of cover reactions did not provide any particular contrast in behaviour of sockeye fry and smolt. Consequently experiments were designed for the observation of fish under low light intensities and in an environment where they could swim at considerable depths.

Two different tanks were used to study depth preference. The best picture was obtained with a water column 180 cm. high, 60 cm. wide and 22.5 cm. from front to back. This tank is constructed of sheet aluminum, has a plate-glass front, and, on one side, four taps (spaced at 30-cm. intervals from the bottom) and an opening 10 cm. in diameter. The latter opening, used for removing fish and cleaning the tank, is situated 2 cm. from the bottom and is closed with an aluminum plate. The tank was located so that light entered only from above.

Observations were made from a darkened compartment in front of the glass window. Thermometers were located near the top and bottom of the tank. Temperature gradients did not develop while studying smolt. With the fry, which are less active and smaller, a gradient of about 1°C. could not be avoided when temperatures were high at midday. However, by partially draining the tank and circulating fresh water through it after each set of observations, gradients were avoided at other times. There was no continuous flow of water through the tank between observations. The maximum period (12 hours during the night) with no change of water resulted in a reduction of oxygen to not less than 6.1 mg. oxygen per litre in experiments with smolts (temp. 13°C.). The reduction was less with fry and no oxygen gradients were detected. Light intensity at the surface varied diurnally but was not greater than 150 foot-candles (range 5–150 foot-candles at observation times). In the bottom 30-cm. area of the tank light values ranged from approximately 0.1 to 2 foot-candles as measured in the empty tank.

Groups of fish were placed in the column during the evening and observations commenced at 7:00 a.m. the next day and continued for nine of the standard 15-minute observation periods. Positions were recorded at one-minute intervals. Duplicate experiments on each species and each age group involved groups of 50 fry (sockeye, chum and coho) and 12 smolts (sockeye and coho). The data are summarized in Figure 3.

At least 50 per cent of the sockeye fry (usually about 80 per cent) were consistently found in the bottom 30 cm. of the column. Here, the individuals form an inactive group oriented in the characteristic manner previously described. In contrast, chum and coho fry are conspicuously active and, although coho are nearer the surface, both groups are above the sockeye. The contrast between sockeye fry and the other two groups of fry was even more marked in another experiment where the three species were placed together in equal numbers (15 each) in the tank. In this case, 94 per cent of the sockeye remained quietly in the bottom area. Aline Redlich, working at the University of British Columbia on a research grant from the National Research Council of Canada, obtained a similar distribution of the species. Her unpublished data are summarized in Figure 4.

Sockeye smolts are the most active of the groups studied in the tank and in strong contrast to the inactive sockeye fry. Sockeye smolts are notably active in all the different experiments, but in the 180-cm. water column their activity is extreme. All individuals swim straight up and down at great speed. They were never motionless during these observations. This activity results in close to random distribution as measured by chi-square values of 19 and 13 for the two experiments (45 degrees of freedom, tabled chi-square at 0.01 level, 69.86). Coho smolts show a similar distribution when tested in the same way (values of 52 and 30) but are, on the whole, nearer the surface than the sockeye (Figure 3) and do not move with the same speed and regularity. Coho smolts, in contrast to coho fry, are deeper in the water column and also in the tank used by Miss Redlich (Figure 4).

A similar but less detailed picture was obtained with a depth-preference box in which fish could swim at different levels and be observed from above. The box was made with 15-mm. plywood sides and 5-cm. planking on bottom and ends. The greatest outside dimensions were 180 cm. long, 120 cm. deep, and 28.5 cm. wide. The area was divided into three depths by two steps, as shown in Figures 5 and 6. Water was 5.0 cm. deep at the shallow end, 30 cm. deep in the middle area and 105 cm. deep at the deepest end. Water entered at the bottom of the deep end and was turned off 30 minutes prior to observation. Comparisons with a thermometer fitted in the wall near the bottom of the box showed that this procedure gave uniform temperatures throughout. In the second

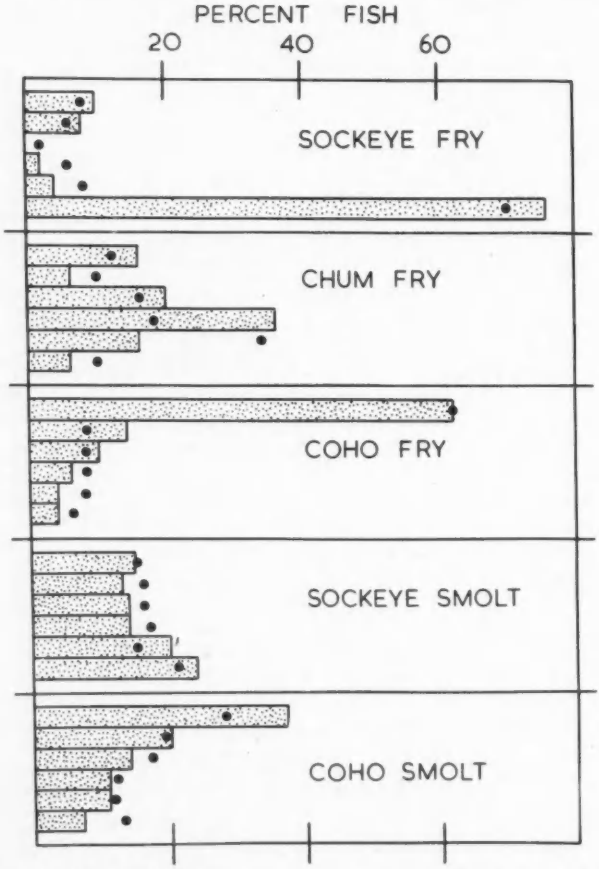

FIGURE 3. Distribution of salmon in a 180-cm. water column. Series of 6 bars for each variety of fish gives the percentage of fish in the 6 areas from top to bottom of the tank for the first series of experiments (June 5–17); series of solid circles are for the duplicate experiments (July 10–19).

or main series of experiments the dark plank bottoms were covered with sheet aluminum for ease and accuracy in recording. No particular differences were noted in behaviour when the bright bottom was used. The light intensity varied diurnally but, over the surface of the box, never rose above 50 foot-candles and was usually less than one-half this.

Distribution of 15 fish in this box was recorded for the standard 15-minute periods five times per day. In the first series of experiments records were made at one-minute intervals for periods of two days. In the second series, duplicate experiments were carried out for one day with observations at 30-second intervals.

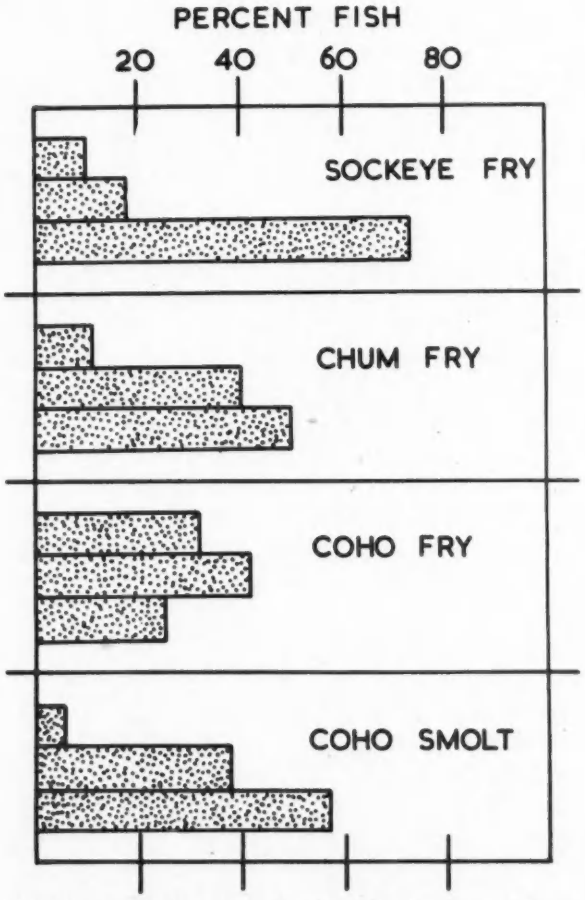

FIGURE 4. Distribution of salmon in a glass-fronted tank 90 cm. high, 65 cm. wide and 50 cm. from front to back. Three bars for each variety of fish give the percentage of the fish in 3 equal areas from top to bottom of the tank. Values are based on more than 2,000 positions in each case. Data obtained by Aline Redlich, June and July, 1951.

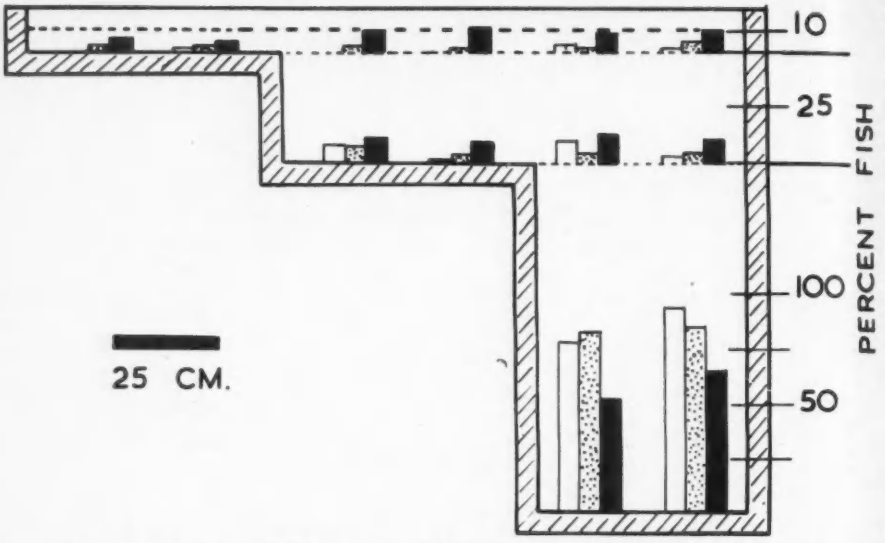

FIGURE 5. Location of sockeye, chum and coho fry in the depth-preference box. Open bars, chum fry; stippled bars, sockeye fry; solid bars, coho fry. Two series are shown in each of the three depth areas; the series on the left was obtained with aluminum-coated floors; the series on right, with dark plank floors.

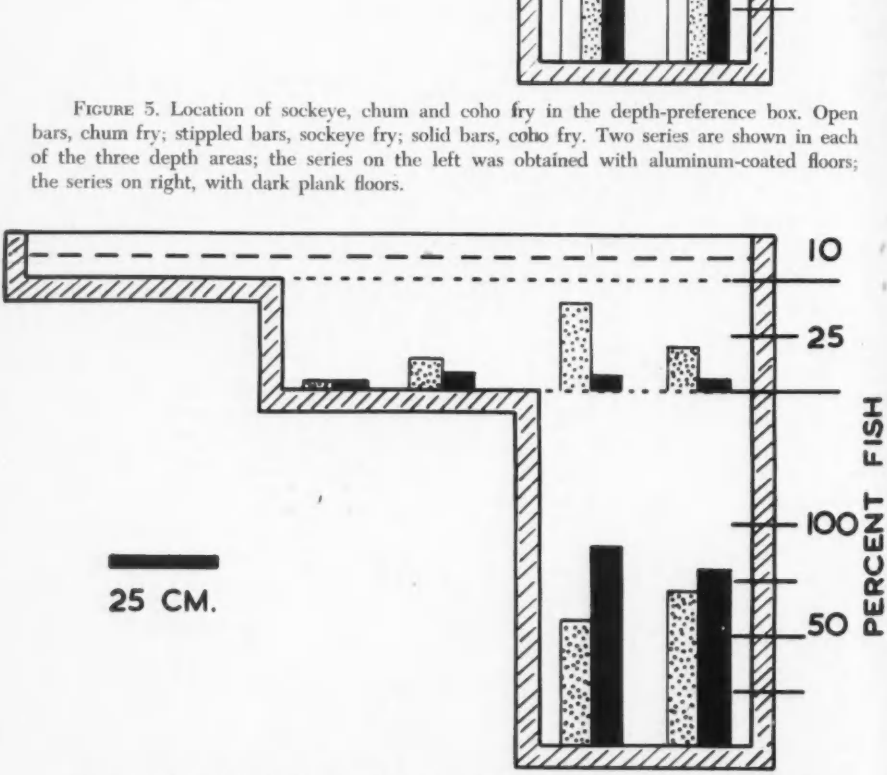

FIGURE 6. Location of sockeye and coho smolts in the depth-preference box. Solid bars, coho smolts; stippled bars, sockeye smolts. Two series of data shown in each depth area; the series on the left was obtained with dark plank floors; the series on the right, with aluminum-covered floors.

It was not possible to see fish far below level 2 in the deep end, but their number could be estimated by difference and totals checked at the end of the experiment.

Reactions of sockeye fry have been compared with chum and coho fry in Figure 5, and sockeye smolts and coho smolts are compared in Figure 6. Percentages are based on three groups of fish of each kind or a total of 450 positions for each of the five kinds of fish. The data confirm those obtained with the glass-faced water columns. Sockeye smolts are again nearer the surface than are the sockeye fry. Sockeye smolts do not come into the shallows as coho fry do but they frequently rise into the waters above the deepest area and occasionally swim into the mid section. This is probably further evidence of their activity as observed in the 180-cm. column.

Responses to Current

SOCKEYE FRY

In fresh water young sockeye, like other salmon, characteristically respond to a sudden increase in water flow by swimming against the current. Quantitative data were mostly obtained from a study of the reactions of fry to turbulence created by forcing water through large glass tubes. The apparatus consisted of a pair of glass tubes (50 or 65 mm. in diameter and 60 cm. long) located side by side in the inflow end of a 225-cm. trough. Water flowing into one or other of the pair of tubes creates a complex turbulence within the tube and the area of water below the tubes. Paired troughs were used for comparative analyses, the tube used as current tube alternated from trial to trial and the order for flows of different magnitude established from random numbers. Additional details of the apparatus and procedures are given elsewhere (MacKinnon and Hoar, 1953).

The reaction of sockeye fry to turbulence is similar to that of other salmon studied (MacKinnon and Hoar, 1953). The progressive rise in intensity of response with time is shown in Figure 7. The graph is based on three observation

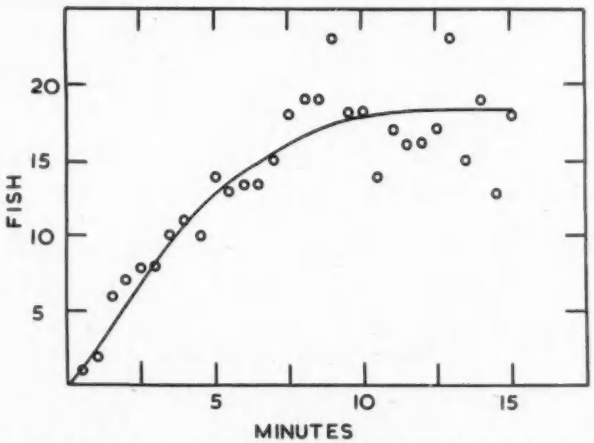

Figure 7. Response of sockeye fry to sudden turbulence measured in terms of total fish for 3 experiments counted in the current tube at half-minute intervals after flow started. Flow, 4,000-5,000 ml./min.; temperature, 11.5°–16.0° C.; further description in text.

periods with groups of fry in the 65-mm.-tube apparatus using currents which, as shown below, cause the greatest number of fish to respond.

Response in relation to different flow conditions is shown in Figure 8. The three line graphs show the reaction of a group of 20 sockeye fry studied in 10 different turbulences for periods of 15 minutes during a 48-hour period. Broken lines indicate the upper and lower limits of response, whereas the continuous-trend line was drawn by joining points obtained from moving averages of two taken twice. A maximum response is elicited by the turbulence developed with 4,000 ml. per minute. The histogram, based on a comparable study of four groups of fish in the 50-mm.-tube apparatus, shows a similar picture. Ten flow conditions were used with each group of fish, making a total of 40 observation

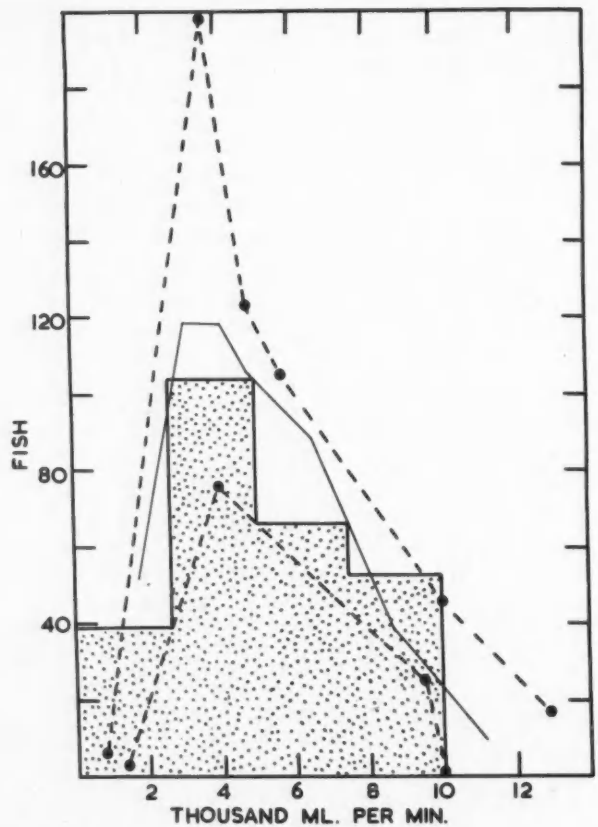

FIGURE 8. Number of fish counted in turbulent waters of glass tubes during 15 minutes observation after initiating the various flows indicated (positions recorded every half minute); further description in text.

periods. In the histogram, data are grouped according to flow intervals of 2,500 ml. up to a maximum of about 10,000 ml. per minute.

Like chum and coho fry previously compared in this apparatus (MacKinnon and Hoar, 1953), sockeye fry show no evidence of adaptation to moderate turbulence during a two-hour period. Three groups of fry were compared in turbulences which developed suddenly with water flow of 2,000 ml./min. and in turbulences of the same order operating for two hours prior to observation. The two conditions alternated with each group throughout the 10 observation periods. The total number of fry counted in the current tube in all experiments, less the number in the quiet tube, was 547 when no flow preceded the study and 1,321 after a flow of two hours. The two values are strictly comparable as to number of observations. A greater response with prolonged stimulation is indicated. Chum fry compared at the same time (identical light and temperature) gave values which were higher but of the same general order (1,347 and 2,108). Differences in size and ability to swim may account for the variation between the two species.

Sockeye, like chum and coho fry (MacKinnon and Hoar, 1953), will swim through an area of rapid shallow water from a downstream to an upstream pool. The apparatus, detailed elsewhere (MacKinnon and Hoar, 1953), stimulates fish to swim for about 15 cm. through water which is so shallow that their backs are exposed. Comparative data for chum and sockeye fry, presented in Table VI,

TABLE VI. Movement of groups of 10 fry from a downstream to an upstream pool through shallow water, during the first 15 minutes and during the whole 2 hours of each trial. A, 14 trials, 9°–13°C., June 13–18, 1952; B, 7 trials, 17°–23°C., July 9–10, 1952. The maximum possible successes is 10 for each trial.

		Sockeye		Chum	
		Mean	Range	Mean	Range
Number of attempts (15 min.)	A	3.1	0–7	4.4	0–10
	B	5.6	0–13	7.1	1–13
Successes (15 min.)	A	0.6	0–3	3.0	0–8
	B	3.7	0–8	4.6	1–8
Successes (120 min.)	A	3.3	0–10	5.9	1–10
	B	7.4	5–10	7.3	1–10

again suggest a more vigorous response by the chums. The higher values obtained in the July experiments may be due to higher temperatures or the somewhat larger size of the fish. Comparative differences cannot be emphasized but it is clear that sockeye fry make attempts to pass over shallows and that the response is persistent for at least two hours.

SOCKEYE AND COHO SMOLT

Sockeye and coho smolt were compared in three series of different experiments. In the first, groups of 20 fish were studied for one day in the 65-mm.-tube

apparatus and positions plotted at 30-second intervals for the standard observation times. The data, presented in Table VII, series A, show differences between the mean number of fish in the tubes during the 15-minute periods. It was first established in duplicate control experiments that both sockeye and coho smolt showed equal distribution between the two tubes although coho were recorded in the tubes about seven times as often as the sockeye. This latter fact is evidently due to the territorial behaviour of the coho. A dominant individual usually defended the downstream pool forcing the others up into the tube area. It may also be related to thigmotactic behaviour described above. It was next shown that when the flow is suddenly changed from zero to 8,000 ml. per minute the

TABLE VII. Reactions of smolts to current. Series A, 20 fish per group with 65-mm.-tube apparatus; series B, 12 fish per group with troughs divided into two channels. Four groups were studied in each case except series A controls, where 2 groups were studied. The "P" values represent the probability that a difference as great or greater than the observed could have occurred by chance.

	No. of trials	Coho				Sockeye			
		Mean no. of fish in:		t	P	Mean no. of fish in:		t	P
		Current	No flow			Current	No flow		
SERIES A									
Controls	10	70.5	54	1.60	0.13	9.5	7	0.81	0.42
Sudden flow	20	26	37	2.58	0.02[b]	37	6	9.01	<0.01[a]
Continuous flow	20	7.7	20.3	2.36	0.02[b]	11	2.5	4.31	<0.01[a]
SERIES B									
Controls	16	21	16	0.98	0.35	18	25	1.25	0.25
Flow 10 min.	16	25	17	1.43	0.14	28	13	5.00	<0.01[a]
Flow 30 min.	16	24	21	0.59	>0.5	30	11	5.04	<0.01[a]

[a]Greater number in area of current (.01 level).
[b]Greater number in quiet area (.02 level).

sockeye smolt show a strong preference for the fast water, being found in the "current tube" about four times more frequently than in the control experiments. Coho smolt, on the other hand, move into the tubes less frequently than they did in control experiments, are more frequently in the tube area and, most strikingly, show an avoidance of the fast water. Finally, with a continuous flow of 8,000 ml./min. sockeye still move into the current tube more frequently, whereas coho show the reverse reaction. In both cases, however, the response is less marked with prolonged continuous flow.

In these experiments, dissolved oxygen was checked frequently by the standard Winkler method. With both groups the expected fall in dissolved oxygen was noted when the flow was turned off for three hours (maximum period). Sockeye smolt, which rarely move into the tubes unless stimulated, produce no gradient in different parts of the system, although dissolved oxygen

fell from a value of approximately 9.0 mg. to 7.0 mg. per litre at 15° (near maximum working temperature). The dissolved oxygen rises rapidly in the tube of quiet water when flow is initiated in the "current tube" (7.0 mg. at 0 minutes; 8.0 mg. at 5 minutes; 8.3 mg. at 10 and 15 minutes). Coho smolt produce a more extreme condition. The downstream pool is normally defended and most of the fish driven into the tubes. With no flow for four hours (one hour longer than the usual time interval for no flow) oxygen at 13.5°C. was reduced to 4.5 and 5.4 mg. per litre in the tubes with 6.4 mg. per litre in the downstream pool. With a flow of 8,000 ml. per minute (only flow used for the smolt) the oxygen in the "quiet tube" rose to 5.5, 5.9 and 7.6 mg. O_2 at 5, 10 and 15 minutes respectively. With continuous flows the maximum differences which developed in the two tubes amounted to 1.1 mg. O_2 per litre. It is thus evident that there were gradients in oxygen at certain times, and although Lindroth's (1949) findings based on Atlantic salmon would suggest that the supply was adequate, it is possible that this factor modified the results.

The second series of experiments was designed, therefore, to eliminate the oxygen gradients which develop in glass tubes and to produce a different flow condition. A pair of 225-cm. troughs, located side by side, were divided longitudinally for half their length by a piece of aluminum-coated plywood cemented to the midline of the floor and the inlet end of the trough. About 8,500 ml. of water per minute flowed through 13-mm.-diameter glass tubes hanging almost vertically in the inlet (closed) end of one or other of the channels in the divided end of the trough. The inlet tube was alternated from side to side in successive trials and the two kinds of smolts alternated from trough to trough in successive experiments. Flow conditions in this apparatus were related to those in the large glass tubes (MacKinnon and Hoar, 1953) by injecting dye into the inflow. The front of a mass of 5 ml. of concentrated methylene blue reaches the lower boundary of the four successive quarter sections of the trough in 5, 50, 120 and 180 seconds. The inflow channel is free of dye in about five minutes and little or no dye is observed in the quiet channel. This would seem to be a less turbulent situation than that used in the first series of experiments.

Twenty fish were placed in the troughs in the evening and records taken at 7:00 a.m., 11:00 a.m., 3:00 p.m. and 7:00 p.m. the next day. New groups were taken each day. Five positions were recorded at one-minute intervals, the water flow was then adjusted, without startling the fish, to about 8,500 ml./min. and 10 minutes later, another six positions plotted. A final record was made after 30 minutes, the flow then turned off and the inlet tubes changed in preparation for the next test. Values presented in Table VII, series B, are means for total number of fish counted in the channels during the five minutes.

Again, it is evident that there is no preference for one channel or the other in the control experiments and that, with the flow used, only the sockeye enter the current channel in preference to the quiet channel. Observations show that, as the currents develop within the apparatus, sockeye smolt are stimulated to greatly increased activity and move to and fro in the trough, entering and leaving both channels but more frequently being directed into rapid water.

Coho smolts, on the other hand, show little change in behaviour but maintain their positions in corners and near walls and carry on defence of territory. This experiment does not show that coho avoid the current.[3]

In the third series of experiments, smolts were stimulated to move from a downstream to an upstream pool through a shallow rapids as previously described for fry. In this series, 10 sockeye and 10 coho smolts were placed together in the downstream pool. Their initial reaction was similar to that of the fry. They quickly dart under cover and emerge within five minutes to swim back and forth between the rapids and cover. Individuals, approaching the rapids, struggle over them more and more frequently each minute. Fish were observed for 15-minute periods. In 11 trials, involving five different groups of fish, 162 sockeye attempted to cross the rapids and 60 attained the upper pool. In contrast, only 83 coho made the attempt and 13 succeeded. Since the coho has a deeper body the success of the sockeye might seem to be related to its ability to swim in shallows. However, the relative number of attempts is greater for sockeye even though the ratio of attempts to successes is less for sockeye (2.7) than coho (6.4). The difference between the two species is very evident in a qualitative way. Sockeye make such vigorous struggles on the ramp that the water becomes obviously silvered with their loosened scales. Coho, on the other hand, swim onto the ramp in a leisurely fashion and fall back. The findings are in agreement with those of the other series of experiments and with the earlier conclusions of MacKinnon and Hoar (1953) regarding coho fry.

DISCUSSION

The life history of the sockeye has now been studied scientifically for almost half a century (Gilbert, 1914). Numerous observations and correlations have been recorded. However, as Clemens (1951) points out in a recent article, there is still considerable speculation about the details of the downstream movement even though the main factors involved are now reasonably clear. It is, for example, agreed that the rate and time of downstream movement are influenced in one way or another by temperature, light, precipitation and currents (Foerster, 1937; Robertson, 1949). These factors, however, have been shown to control the rate of migration of many different anadromous salmonids. Pritchard (1944) found the pink salmon fry migration limited to the hours of darkness and accelerated, but not initiated, by rainfall. White (1940) found that a rise in temperature and low light intensity, rather than rainfall, influenced the descent of Atlantic salmon smolts, whereas sea trout (*Salvelinus fontinalis*) descend to the sea with a rising temperature (White, 1941). These examples could be multiplied. They emphasize the fact that such variables control the time and rate of migration but do not explain fundamental differences which exist among

[3]In a series of identical experiments carried out at Lakelse Lake, British Columbia, in June, 1953, both coho smolts and sockeye smolts showed a marked preference for the channel of rapid water. However, the sockeye smolts attained the peak response more rapidly (within the first 10 minutes) and the total responses of the sockeye smolts after 10 minutes and after 30 minutes were about twice as great as those of the coho smolts.

species. Variations in the extent of lake residence of sockeye salmon, for example, and knowledge of mechanisms initiating the eventual migration of the juveniles are still largely conjectural.

In the present study, controlling factors such as temperature and precipitation are not emphasized. An attempt has, however, been made to broaden the understanding of migration by describing mechanisms of behaviour which are responsible for those activities of sockeye that are distinct from the activities of other species of *Oncorhynchus*.

Depth and Light Preference

The first group of activities involved in the distinctive life history of juvenile sockeye is related to their cover reactions, depth and light preferences. Sockeye fry prefer deep water and remain under cover when in shallow water and strong light. Both depth preference and cover reaction may be responses to light. Miles Keenleyside, working at the University of British Columbia on a National Research Council grant, has shown that very young sockeye fry are negatively phototactic in a horizontal light gradient. His experiments, carried out with the same apparatus and under identical conditions to those reported earlier for several other salmon (Hoar, MacKinnon and Redlich, 1952) show a statistically significant movement of the sockeye toward the dark end of the gradient (Table VIII).

Table VIII. Mean number of sockeye fry in each half, A and B, of a 150-cm. horizontal light gradient with illumination of 40 foot-candles when uniformly lighted, and with illumination decreasing from 28 to less than 1 foot-candle along its length when only one end is lighted. 7 groups with 12 fish in each group were observed for 10 periods of 15 minutes duration in each case. From data obtained by Miles Keenleyside.

	Uniform illumination	Area A illuminated	Area B illuminated
Mean number fish in A	178.6	140.1	233.9
Mean number fish in B	181.4	219.9	126.1
t	0.154	4.825	11.529
P	7.5	<0.01	<0.01

It may be presumed that sockeye fry, reacting in this way, will be in shady parts of a stream, or under cover provided by stones, logs and overhanging vegetation. They will emerge if the light intensity is not too great and travel slowly about in quiet water or stem the currents. During the hours of darkness, when rheotactic responses are greatly reduced or eliminated they will be displaced downstream. The experiments show that sockeye fry may travel persistently upstream with optimum flows. Where long distances are involved the net movement will probably be downstream. Chum fry, in contrast to sockeye, do not show a marked cover reaction and do prefer more intense light (Hoar *et al.*, 1952). It is suggested that they move into brighter areas of faster water during

the day so that their downstream displacement at night will be even more likely than that of the sockeye.

Depth-preference experiments indicate that sockeye fry will move into deep water when they arrive in a lake. Continued residence within the lake is assured if they move to deep water and are relatively inactive as in the experimental tanks. The present experiments do not show how deep sockeye fry will go in a lake. On the basis of experiments with the 180-cm. tank and Keenleyside's studies (Table VIII) they may be expected to live at light intensities of one foot-candle or less. J. G. Hunter's studies at Port John indicate that fry do not go to great depths but are found in the upper nine metres. His data, as yet unpublished, were obtained from an 18-metre column of fine net with gates which could be closed at different levels.

Sockeye smolts, like sockeye fry, show a marked cover reaction and a tendency to swim in deep water. In our experiments, however, they are often nearer the surface than the fry. This may be entirely due to their marked activity which results in a wider vertical distribution particularly at low light intensities. In general, however, larger individuals of a species of fish seem to be deeper than the smaller ones. Huntsman (1948) found that this was true for Atlantic salmon and the present study shows that coho behave in this way (Figures 3 and 4). Unpublished data indicate that underyearling chums move into deeper water as they increase in size. The surfacing of the sockeye smolts would, then, appear to be a somewhat peculiar phenomenon. Although it may be due to the marked activity rather than a change in light or depth preference, it would seem to be important in explaining movement from the lake. The more superficial location in the lakes, associated with marked activity both day and night will eventually bring the fish within the influence of waters flowing out of the lakes. If the water is shallow enough to provide visual cues strong responses to current will presumably hold them there during the day whereas they will be carried into the streams during hours of darkness, and be moved seaward under the same forces that moved them into the lakes or that move chum salmon to sea.

Aggregation and General Activity

The second of the distinctive activities of juvenile sockeye, pertinent to an understanding of migration, is associated with the nature of the aggregating behaviour. Sockeye, like other Pacific salmon (pink and chum) which as underyearlings assume a pelagic life, are schooling fish. However, the aggregates of sockeye fry, in contrast to those of pink and chum, are less active, swimming more slowly and wandering less frequently. They remain in relatively stationary or slowly moving groups during the first months of their life. It is suggested that this, in association with their depth preference, will localize them within a lake at a time when they are small and the spring run-off from the lake might otherwise carry them seaward.

On the other hand yearlings are extremely active, swimming almost continuously and coming into surface waters at low light intensities. This surge in

activity is probably associated with the smolt transformation. Thyroid stimulation is characteristic of sockeye smolt (Hoar and Bell, 1950), and thyroxine increases the rate of swimming (Hoar, MacKinnon and Redlich, 1952). As Clemens (1951) suggests, the activity of the smolts, along with a net movement of the water toward the outlet of the lake, eventually brings the fish to the outlet and into the stream.

The nipping behaviour of sockeye smolts requires comment. Nipping is part of the regular activities of juvenile coho salmon and trout in fresh water. It is an aggressive type of behaviour, associated with defence of specific territories, and resulting in dispersion of fish in the area. It is rarely observed in the juvenile schooling salmon. Sockeye smolts show it not infrequently, but sockeye fry and underyearling chum and pink salmon very rarely. In the latter groups, nipping appears occasionally when temperatures are elevated or the fish are long confined in limited areas. In sockeye smolts this behaviour is irregular in occurrence and erratic in appearance. It is more frequent in some types of confinement than others, and inconsistently associated with defence of territory. Such behaviour, in the schooling juvenile Pacific salmon (sockeye, chum and pink), has the characteristics of a *displacement reaction* (Armstrong, 1950; Tinbergen and van Iersel, 1947). Aggressive behaviour is a part of the normal behaviour of sexually mature sockeye, chum and pink salmon but in juveniles is performed "out of the functional context of . . . behaviour-patterns to which it is normally related . . ." (Armstrong, 1950).

Breder's (1951) analysis of aggressive and aggregating behaviour is of interest. He points out that true schooling fish have little or no peck-order and that this aggressive behaviour is the dispersive influence in more solitary forms. Juvenile Pacific salmon in fresh water show various degrees of such relationship, from the extremely aggressive coho fry, through the much less aggressive coho smolts to the sockeye smolts and the non-aggressive sockeye, chum and pink fry. It may be noted here that the aggressive behaviour displayed by coho does not produce an orderly arrangement of pecking with respect to particular individuals and has, therefore, been termed *nipping* (Hoar, 1951).

Responses to Current

Finally, a variable response to current is important in explaining the different life histories of Pacific salmon. Juvenile salmon in fresh water are usually positively rheotactic. This positive response, in brook trout at any rate, is apparent as soon as the fish hatches and before the yolk-sac is absorbed (White, 1915). In travelling about during the day salmon may be carried or may dart for short distances with the current but the over-all response where waters are shallow and the bottom visible is one of holding position or moving against the current. Negative rheotaxis and persistent swimming downstream were not observed in these experiments under normal conditions of temperature. They do, however, appear when temperatures are suddenly elevated (Hoar, 1951 and unpublished data) even though the temperatures are considerably below the

lethal range and were frequently observed in underyearling salmon held in the sea (unpublished data). Although positive rheotaxis in fresh water is general, different species are stimulated to varying degrees by currents of any particular magnitude (MacKinnon and Hoar, 1953). Species such as chum fry and sockeye smolt which move persistently into strong currents will be displaced downstream more rapidly in reduced light than those species such as coho which adapt to currents or are not so markedly stimulated by them.

Sockeye smolts, in contrast to coho smolts, not only make a stronger positive response to current but show a marked increase in general activity when flow is altered. Coho usually occupy their same territories and hold position. This difference in general activity is probably important in initiating the movement of sockeye from lakes. No doubt it also accounts in part for the greater precision and speed of downstream migration by sockeye smolts. J. G. Hunter, in charge of the Port John Station, has kindly supplied data on the movement of smolts through a trap at the mouth of Hooknose Creek. The sockeye smolt migration is of shorter duration than that of the coho smolts. Although the peak of coho migration is likely to come at a time of high water and coincide with the sockeye migration, the downstream movement of coho starts earlier and is more prolonged.

Chum Salmon Migration through Lakes

Adult chum salmon sometimes pass through lakes and spawn in tributary streams. It is not known whether the fry pass through the lakes or perish there. There are, however, three factors which may take chum fry through a lake into the outflow while the sockeye fry remain behind. In the first place, chum fry are more frequently moving, swim more rapidly and will cover a greater area than sockeye fry. This may be due to the difference in size but studies of the thyroid gland indicate that the chum fry in fresh water is under a metabolic stress which may increase activity (Hoar and Bell, 1950). In the second place, chums show a less pronounced response to cover and will be in stronger light than the sockeye. Although they evidently avoid very shallow water they respond positively to light of moderate intensity (Hoar *et al.*, 1952), and will be nearer the surface than the sockeye. In the third place, there is some evidence that chum fry make a stronger positive response to current (Table VI and page 87). Their greater activity nearer the surface and slow adaptation to faster water may bring them eventually to the outlet of the lake where they will be carried seaward. It has never been demonstrated that numbers of chum fry do come through lakes. However, their behaviour is more apt to bring them through a lake than that of the sockeye fry.

Upstream Migration by Sockeye Fry

Another interesting problem arises from facts known of sockeye life history. In some areas adult sockeye spawn below a lake, and resulting fry are observed moving upstream toward the lake. In the present experiments, sockeye fry under-

take prolonged excursions in the troughs, move vigorously into turbulences of certain intensities, and migrate upstream over rapids. It is then possible that peculiar flow conditions would lead them for considerable distances upstream. However, their behaviour in currents is similar to that of chums and it is hard to see how these responses will, in one case, result in downstream movement and, in another, movement in the reverse direction. The preference which sockeye fry show for cover and low light intensity will presumably keep them down during the day and bring them out when light intensities are low and they are more likely to be displaced downstream. Exploring activity alone would as frequently take them in one direction as the other. Their sharp response to current and positive rheotropism would be expected to keep them near one place during the day and lead to downstream movement at night. It is suggested that movement of sockeye fry *of size and age used in these experiments* will be predominantly downstream. Larger underyearling sockeye (approximately 50 mm. fork length) which had been retained three months in sea water were much nearer the surface when in deep water and showed a negative response to current (unpublished data). Larger and older underyearling sockeye from fresh water should be compared.

It is of interest that in Hooknose Creek downstream movement of sockeye fry from the creek into the sea is not uncommon. In the spring of 1952 almost 3 per cent of the total sockeye fry production of the river system passed through the downstream trap at head of tide. It is not known whether the eggs which produced these fry were deposited below the lake or in streams tributary to the lake.

Additional Observations on Chum Fry

This investigation permits a more accurate interpretation of the juvenile chum salmon's behaviour than was possible at the time of the preceding paper (Hoar, 1951). Evidence available at that time led to statements that their "activity takes them into the swiftest currents," that "they do not seek cover" or "have any relation to cover or solid objects in the areas where they are found". The latter statements concerning cover reaction have already been qualified in this paper but location of chums in reference to currents requires further comment.

MacKinnon and Hoar (1953) have shown that chums, like other Pacific salmon, show a maximum response in relation to some particular flow. Although the optimum current is greater for chum fry than coho or small sockeye it is not likely that chums will be in the "swiftest currents". The evidence, however, suggests that they will be in open and relatively swift parts of the stream during the day. In 1952 groups of several hundred chums were released regularly at different specified points in the lower 200 metres of Hooknose Creek. The majority held position during the day of release when placed in open places along the bank where the water flowed swiftly but smoothly and was not "boiling". They had always disappeared by the next morning.

SUMMARY

1. Sockeye fry have a strong cover reaction, a preference for low light intensities and deep water. They form relatively inactive or slowly moving schools and respond positively and vigorously to currents. It is postulated that downstream displacement occurs at low light intensities when fry emerge from cover and darkness eliminates rheotactic responses. Further, it is suggested that sockeye fry remain in the lakes because of their relative inactivity and preference for deep water.
2. Chum fry, in contrast to sockeye fry, are more active, swim more rapidly, prefer stronger light and have a less marked cover reaction.
3. Sockeye smolts are extremely active in comparison with sockeye fry. They are found in shallow as well as deeper water and are markedly stimulated by currents. Their movements presumably carry them to the outlet of the lake where they are displaced seaward at night when rheotactic responses are reduced.
4. Coho smolts, in contrast to sockeye smolts, are less active, show marked territorial behaviour, rest near solid objects, and are not as markedly stimulated to movement by current. These observations seem to explain the relatively slower downstream movement of coho smolts.
5. Aggressive behaviour in juvenile chum, pink and sockeye salmon is considered to be a "displacement reaction".

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J. G. Hunter, in charge of the Port John field station of the Fisheries Research Board has extended a helping hand on many occasions. R. C. Wilson, chief technician at Port John, enthusiastically assembled laboratory facilities from the flotsam and jetsam of that rugged country. Such co-operation has expedited the study at every stage.

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Station List of the *Calanus* Expeditions, 1951-52, together with Frobisher Bay Stations, 1948, 1950 and 1951, and Resolution Island Stations, 1950[1]

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"CALANUS" SERIES, NO. 4

ABSTRACT

A list is given of 61 stations where biological or oceanographic observations or collections were made by the *Calanus* in Ungava Bay, Frobisher Bay, Cumberland Sound and adjacent waters, during the 1951 and 1952 seasons. Five additional stations, occupied independently from the *Calanus* in Frobisher Bay in 1948, 1950 and 1951, and at Resolution Island in 1950, are included.

INTRODUCTION

The "Station List of the *Calanus* Expeditions, 1947–50" has been published (*J. Fish. Res. Bd. Canada*, 9, 65–82, 1952), and included stations occupied in Ungava Bay and adjacent waters. In 1951 work was begun by the *Calanus* in Frobisher Bay, and was continued there and in Cumberland Sound in 1952. In 1948, 1950 and 1951 stations were occupied in Frobisher Bay, and in 1950 at Resolution Island, by investigations carried out independently from the *Calanus*.

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LIST OF STATIONS

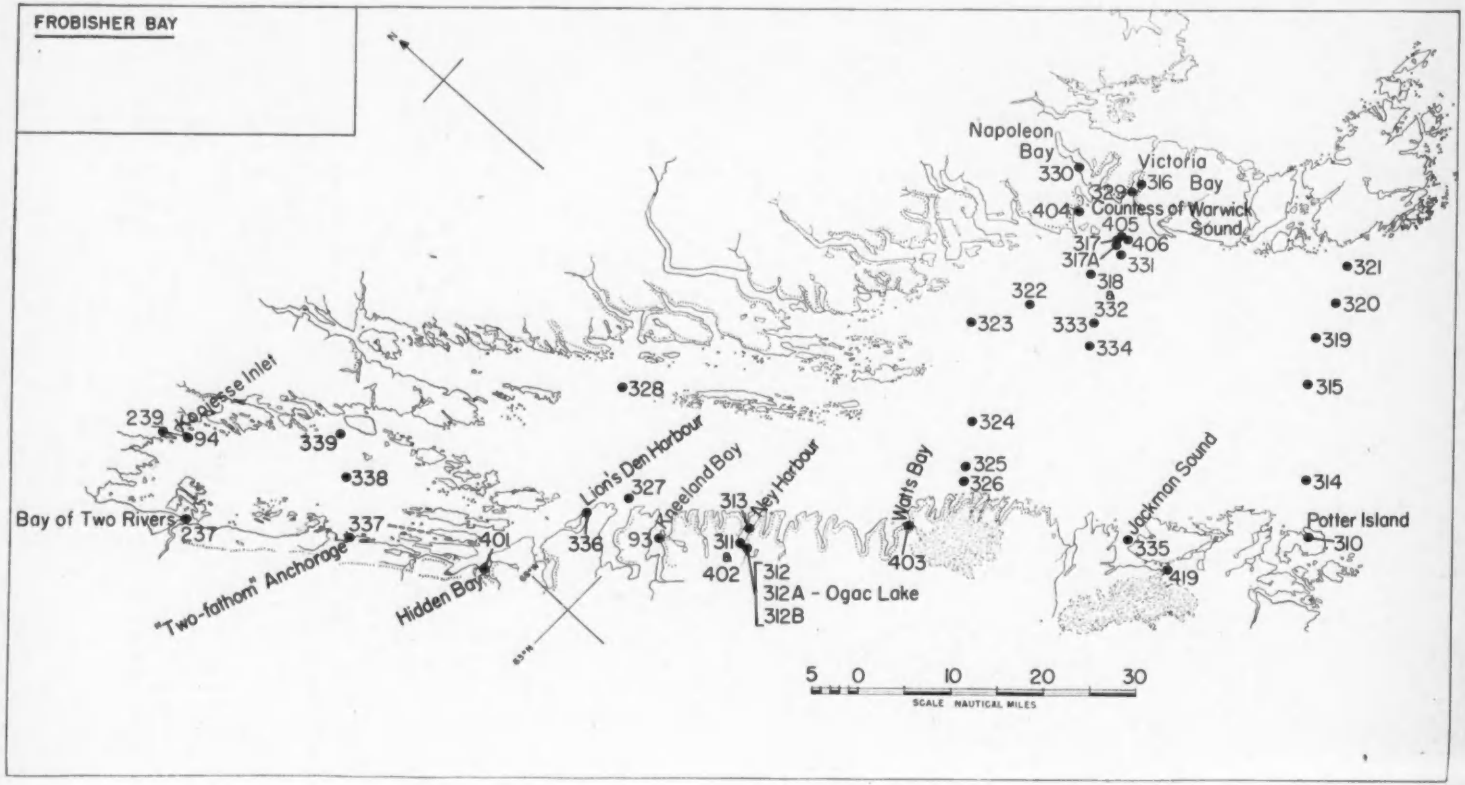
Station	Map location	North Latitude	West Longitude	Depth (*metres*)	Type of station (work done)
	1951				
301	Adlorilik	59°29.5′	65°20′	110	plankton, hydrographic
302	Adlorilik	59°30′	65°16′	45–51	hydrographic
303	west of Adlorilik	59°30′	65°32′	120	plankton, hydrographic
304	mouth of Korok River	58°54′ (approx.)	66°03′ (approx.)	42	plankton
305	Hydrographic section from George River to Akpatok Island	59°19′	66°39′	128	hydrographic
306		59°34′	67°07′	320	hydrographic
307		59°49′	67°34′	255	hydrographic
308		60°03′	68°00′	64	hydrographic
309	Lake Harbour	62°45′ (approx.)	69°40′ (approx.)	22	plankton
				201	plankton
				165	hydrographic
310	Potter Island	62°06.5′	65°52′	—	littoral collecting
				27	plankton
311 & 402	Ney Harbour	62°51.5′	67°21′	9–27	hand line fishing, benthos collecting
312	Ogac Lake	62°51′ (approx.)	67°21′ (approx.)	62	plankton, hydrographic
312A	Ogac Lake	62°51′ (approx.)	67°21′ (approx.)	7–20	plankton, hand line fishing, hydrographic
312B	Ogac Lake	62°51′ (approx.)	67°21′ (approx.)	7–18	hand line fishing
313	Ney Harbour	62°52′	67°18′	183	hydrographic
314	mouth of Frobisher Bay	62°11′	65°42′	338	hydrographic
315	mouth of Frobisher Bay	62°18′	65°25′	263	hydrographic
316	Victoria Bay	62°46′	65°16′	—	littoral collecting
317	Countess of Warwick Sound	62°44′	65°29′	27–36	benthos (dredging)
317A	½ mile from 317	62°44′	65°30′	36	long line fishing

Station	Map location	North Latitude	West Longitude	Depth (*metres*)	Type of station (work done)
318 & 332	southwest of Countess of Warwick Sound	62°43′	65°38′	55	benthos (dredging and trawling), long line fishing, hand line fishing, hydrographic
319	mouth of Frobisher Bay	62°21′	65°16′	113–118 68	benthos (dredging) benthos (dredging)
320	mouth of Frobisher Bay	62°21.5′	65°05′	80	hydrographic
321	mouth of Frobisher Bay	62°23′	64°58′	71	benthos (dredging)
322	10 miles west of Countess of Warwick Sound	62°46′	65°55′	119	benthos (dredging and trawling)
323	hydrographic section across Frobisher Bay	62°49.5′	66°05′	146	hydrographic
324		62°42′	66°23′	329	hydrographic
325		62°39′	66°32.5′	549	hydrographic
326	southwest of 325	62°38′	66°35′	549–640	plankton
327	Upper Frobisher Bay	63°04′	67°31′	more than 640	hydrographic
328	Upper Frobisher Bay	63°12.5′	67°12.5′	274	hydrographic
329	Victoria Bay	62°46′	65°16.5′	183	plankton, benthos (dredging), hydrographic
330	Napoleon Bay	62°52′	65°21′	—	littoral collecting
				shallow	hand line fishing
331	southwest of Countess of Warwick Sound	62°42′ (approx.)	65°31′ (approx.)	77	benthos (trawling)
332 & 318	southwest of Countess of Warwick Sound	62°43′	65°38′	55	benthos (dredging and trawling), long line fishing, hand line fishing, hydrographic

Station	Map location	North Latitude	West Longitude	Depth (*metres*)	Type of station (work done)
333	southwest of Countess of Warwick Sound	62°39′	65°47.5′	104–137	benthos (trawling)
334	southwest of Countess of Warwick Sound	62°38′	65°52′	183–192	benthos (trawling)
335	Jackman Sound	62°21′	66°19′	320	plankton, long line fishing, hydrographic
336	mouth of Lion's Den Harbour	63°06′	67°40′	82	long line fishing
337	"Two-fathom" Anchorage	63°22.5′	68°23′	—	littoral collecting
338	Upper Frobisher Bay	63°27.5′	68°13′	128	hydrographic
339	Upper Frobisher Bay	63°31′	68°07′	109	hydrographic
1952					
401	Hidden Bay	63°10′	68°07′	24	plankton, hand line fishing
402 & 411	Ney Harbour	62°51.5′	67°21′	9–27	hand line fishing, benthos collecting
403	Watts Bay	62°39′	66°51′	14–18	plankton, hand line fishing
404	Countess of Warwick Sound	62°48.5′	65°28′	18	benthos collecting
405	Countess of Warwick Sound	62°46.5′	65°27′	55	long line fishing
406	Countess of Warwick Sound	62°74′	65°26.5′	46	benthos (dredging)
407	Neptune Bay	64°34′	65°17′	228	plankton
				118	hydrographic
408	Hydrographic section across the mouth of Cumberland Sound	64°41.5′	64°55′	396	hydrographic
409		64°49′	64°39′	640(?)	hydrographic
410		64°56.5′	64°22.5′	576	hydrographic
411	south of Nijadluk Harbour	65°01′	64°08′	83–91	plankton

Station	Map location	North Latitude	West Longitude	Depth (*metres*)	Type of Station (work done)
412	Pangnirtung	66°09′	65°44′	—	littoral collecting
				29	plankton
413	Quickstep Harbour	66°12.5′	66°24′	—	littoral collecting
				10	plankton hauling, hand line fishing, benthos collecting
414	2 miles off mouth of Quickstep Harbour	66°11′	66°28′	274–366	plankton
415	west of Quickstep Harbour	66°12.5′	66°23′	73	long line fishing
416	Clearwater Fjord	66°27′	67°11′	274–284	plankton, benthos (dredging), hydrographic
417	Clearwater Fjord	66°26′	67°07′	—	littoral collecting
				36	long line fishing
418	Ptarmigan Fjord	64°50′	65°51.5′	—	littoral collecting
				18–55	plankton, benthos collecting, hand line fishing
419	Jackman Sound	62°15.5′	66°18′	13–18	plankton, benthos collecting, whaling
	1948				
93	Kneeland Bay, Frobisher Bay	62°58′	67°22′	18	plankton
94	Koojesse Inlet and mouth of Sylvia Grinnell River, Frobisher Bay	63°43′ (approx.)	68°32′ (approx.)	0–60	gill net fishing, hand line fishing, plankton, benthos collecting, littoral collecting
	1950				
94	(above)				
237	Bay of Two Rivers, Frobisher Bay	63°37′ (approx.)	68°48′ (approx.)	—	gill net fishing, benthos collecting, littoral collecting
238	Acadia Cove, Resolution Island	61°20′	64°53′	18–36	hand line fishing, long line fishing, benthos collecting, plankton

Station	Map location	North Latitude	West Longitude	Depth (*metres*)	Type of station (work done)
239	Fresh water streams and ponds adjacent to the Sylvia Grinnell River, Frobisher Bay	63°45′ (approx.)	68°36′ (approx.)	—	fresh water collecting
	1951				
94	(above)				
239	(above)				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Napoleon Bay
Victoria Bay
Countess of Warwick Sound
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Koojesse Inlet
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Lion's Den Harbour
Aneeland Bay
Ney Harbour
Watts Bay
Jackman Sound
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Bay of Two Rivers
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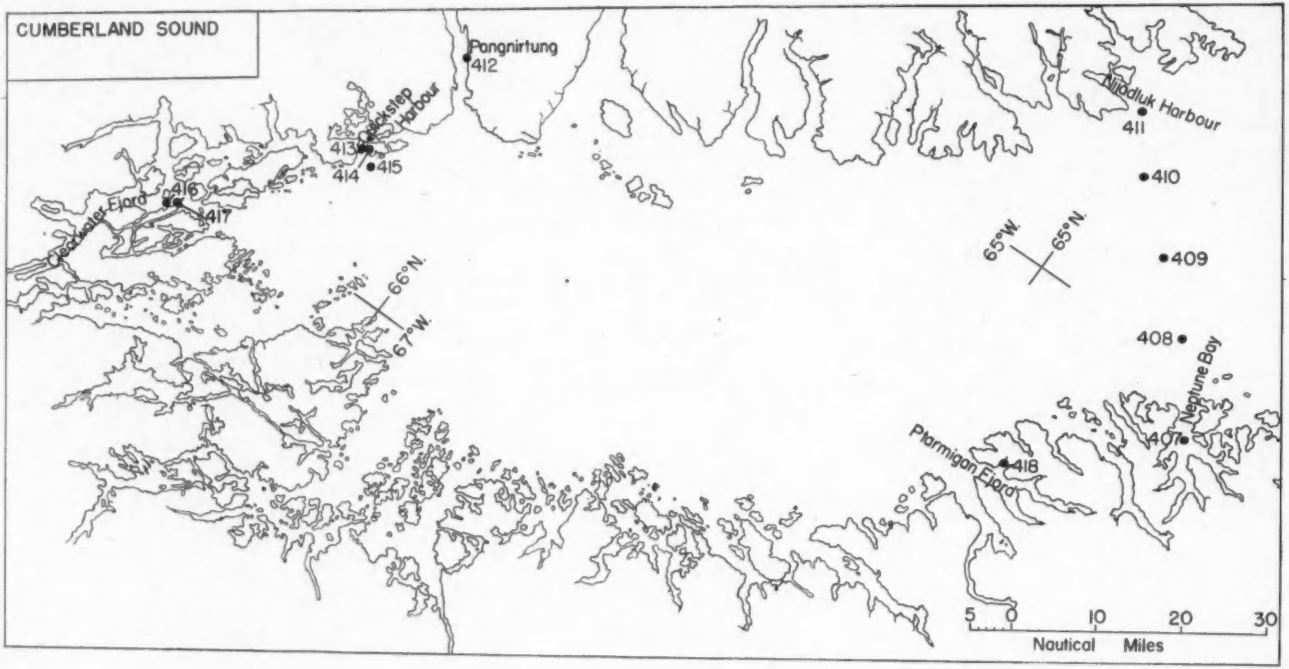
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